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SPACE STATION NEEDS, ATTRIBUTES, AND ARCHITECTURAL OPTIONS

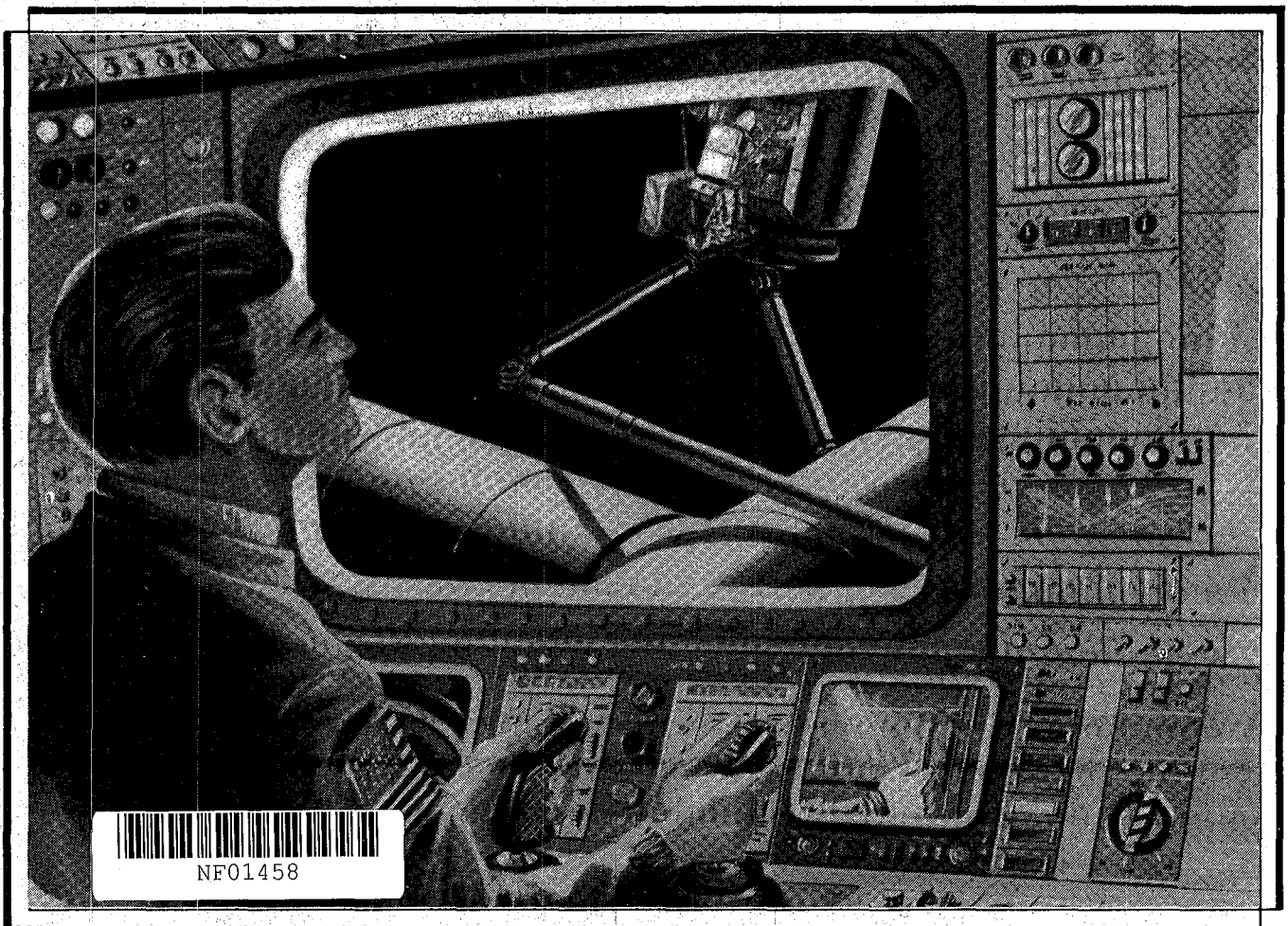
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volume II - book 1

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final technical report

**SPACE STATION
NEEDS, ATTRIBUTES, AND
ARCHITECTURAL OPTIONS**

volume II - book 1
part II — task 1: mission requirements

prepared for
National Aeronautics and Space Administration
Headquarters
Washington, D.C. 20546

under contract NASW-3685
Space Station Task Force
Contracting Study Project Manager — E. Brian Pritchard

by
Grumman Aerospace Corporation
Bethpage, New York 11714

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- FINAL REPORT -

**SPACE STATION
NEEDS, ATTRIBUTES AND ARCHITECTURAL OPTIONS STUDY**

**TASK 1
MISSION REQUIREMENTS**


**SPACE SYSTEMS DIVISION
Valley Forge Space Center
P.O. Box 8555 Philadelphia, PA 19101**

GENERAL  ELECTRIC

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Ronald J. White	-	Life Sciences
R. Thompson Frost	-	Materials Processing/Science
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SECTION 1
INTRODUCTION.

SECTION 1 INTRODUCTION

This appendix summarizes General Electric's input to Grumman Aerospace Corporation concerning the missions in the Commercial and Science and Applications areas allocated to GE under Task 1 of NASA Contract NASW-3685, Space Station Needs, Attributes and Architectural Options. The specific mission areas are:

1. Commercial Materials Processing - including representative missions for producing metallurgical, chemical and biological products.
2. Commercial Earth Observation - represented by a typical carry-on mission amenable to commercialization.
3. Solar/Terrestrial and Resource Observations including missions in geoscience and scientific land observation.
4. Global Environment - including representative missions in meteorology, climatology, ocean science, and atmospheric science.
5. Materials Science - including missions for measuring material properties, studying chemical reactions and utilizing the high vacuum-pumping capacity of space.
6. Life Sciences - includes experiments in biomedicine and animal and plant biology.

In order to minimize overlap, certain mission areas were defined by Grumman while others by GE and Comsat. Thus, the GE missions listed herein constitute approximately one-third of the total number of missions upon which the mission model and architectural options are based.

A different format is used in this volume for describing the commercial missions as compared to the science and application missions. This difference was necessary since the emphasis in the commercial missions is the user orientation and market analysis; whereas the service and application missions require more emphasis on an exposition of the rationale for selecting and performing the scientific investigation using the Space Station. The degree of detail varies between the mission descriptions, primarily due to the availability of sufficient background information upon which to base the

mission concepts. In most cases, an extrapolation in the conceptualization of equipment and operations has been made, using current baseline data, to account for operation in conjunction with the Station; also to ensure compatibility with the time-frame of the 1990s.

General Observations

The results of the analysis suggest several general conclusions that cross over the boundaries of individual mission disciplines. Some of these may be logically predictable; for instance, there are few commercial missions where the operational/commercial phase on-board the Station would not need to be preceded by a research, development and demonstration program. In the case of Materials Processing, this R&D phase could be performed on board the Shuttle or a retrievable vehicle similar to LDEF or Eureka. In the Earth Observation disciplines, this R&D may require a free-flyer or Spacelab pallet. The reason for this is partially due to the early stage of development of most of the instruments for these missions. However, it is also due to the degree of certainty that is required by the investor/user, that the commercial application is viable and profitable. In some cases the Space Station itself would prove to be the best carrier for the "pilot plant" demonstrations. The potential benefits that can accrue from commercial use of the Space Station are very substantial. The accurate assessment of these profits will be facilitated after the initial phases of the mission demonstration phase has been completed.

The Science and Applications mission benefits are more difficult to assess than the commercial ones, due to the indirect nature of their measurable economic advantage. Thus, social benefits need to be translated in economic terms that can be compared with the cost of implementation. This is particularly true in areas of earth observation which are included herein under missions in "Solar/Terrestrial," "Remote Observation," and "Global Environment." Dr. Archibald Park points out that these missions per se do not produce benefits, rather the data that they produce enable the benefit, which materializes when there is in place a system which can extract the requisite information from the sensor and when the information is acted upon by a management infrastructure that makes the appropriate decisions. Recognizing that the contribution of the spaceborne system towards the attainment of the

goal is a fraction (perhaps an order of magnitude of the total system contribution), one is able to examine with proper perspective the startling results of the more recent benefits studies related to earth observation from space. We refer to the study performed by ABT Associates Inc. of Cambridge, Massachusetts in 1981 titled, "The Benefits, Risks and Costs of a Civilian High Resolution Multispectral Satellite-Based Sensing System," which factors in the results and conclusions of both the "Earthsat" Study done for DoI as well as the "Econ" Study done for NASA. In that study, three categories of benefits from space observations would yield \$13.8 billion annually, apportioned as follows:

Mineral and Petroleum Resources	\$ 1.4B
Population (Land Use)	\$10.0B
Basic Foods	\$ 2.4B

Our brief assessment of this study indicates that the benefits may be somewhat high, particularly in the area of "Basic Foods", however, the overall total does not seem unreasonable.

Considering these high potential benefits, worldwide, one must answer the question, "How does the Station fit into this system?" Many of the Science and Application Missions are highly relevant to the areas of Mineral/Petroleum Resources, Population, and Basic Foods; for instance:

1. Advanced Thermal Mapping Applications
2. Advanced E/R Sensing System
3. Soil Moisture and Snow Research
4. Multidiscipline Advanced Land Observation System
5. Ocean Circulation Mission
6. Imaging Radar Experiment
7. Tropical Meteorology Support

Many of these systems are very complex and can benefit from maintenance, repair and periodic reconfiguration, as well as manned monitoring and control to ensure high performance operations. In addition, the Station provides a focus for an integrated global observatory system which permits concurrent or simultaneous measurements of the earth surface and atmosphere, thus enabling the synergistic effect of temporally and spatially correlated data.

The mission descriptions are included in the sections that follow, according to the various discipline categories.

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SECTION 2
USER ALIGNMENT

SECTION 2

USER ALIGNMENT

One of the most important aspects of the study was the establishment of meaningful dialogs with potential users of the Space Station, both outside the General Electric Company and within the commercial sectors of the Company. Table 2-1 shows the key contacts that were made by the GE study team during the study. The general response of the users was positive relative to the desirability of a facility for R&D and, ultimately, commercial space production. Most of the potential users that we contacted expressed their inability to make a commitment and investment in a long-term commercial venture where the scientific/developmental and economic uncertainties make such investment inconsistent with general industry practice, which aims at a rapid turn-around cycle (two to three years), low risk and high return on investment. An exception to this view was expressed by Dr. Vanderhoff, from Lehigh University, who perceives the possibility of near-term commercialization of precise monodisperse latex spheres produced in space through an industrial company such as Dow Chemical Company (Reference: Section 3.2.1).

Table 2-1. User Contact Summary

ORGANIZATION CONTACTED	USER KEY INDIVIDUAL	SUBJECT	RESULTS
WYETH LABORATORIES RADNOR, PA	DR. RUBIN	BIOCHEMICAL SEPARATIONS	DISCUSSIONS DEALT WITH ELECTROPHORESIS AND NEW METHODS OF SEPARATING CELLS. FURTHER STUDY REQUIRED TO DETERMINE THE BENEFIT OF MICRO-GRAVITY IN THIS APPLICATION.
GE MEDICAL SYSTEMS MILWAUKEE, WISC.	R. HUECHEN	X-RAY TARGETS SEGMENT METALLURGY	COULD LEAD TO SPACE RESEARCH AS A NASA JOINT ENDEAVOR. CONTINUED DIALOG PLANNED TO DEVELOP AN APPROACH.
GE CORPORATE R&D	DR. T. DEVINE	IMPROVED TUNGSTEN METALLURGY BY MICROGRAVITY UNDERCOOLED SOLIDIFICATION	RESEARCH WOULD SUPPORT GE MEDICAL X-RAY SYSTEMS TARGETS. GE CR&D WILL EVALUATE THE WORTH OF THIS SPACE RESEARCH PROJECT.
UTAH INTERNATIONAL INC.	DR. J. GABELMAN	REMOTE SENSING FOR MINERAL EXPLORATION	SPACE STATION WILL BE USEFUL IN MINERAL EXPLORATION WHEN AVAILABLE BUT BENEFIT NOT SUFFICIENT TO FUND THE DEVELOPMENT.
RICE UNIVERSITY	PROF. J. MARCRAVE	HIGH TEMPERATURE THERMOPHYSICAL PROPERTIES MEASUREMENTS	POSSIBLE CANDIDATE FOR A SPACE INDUSTRIAL RESEARCH PROJECT. POWER & SAFETY MAY PRECLUDE SPACE SHUTTLE AND REQUIRE SPACE STATION.
NATIONAL BUREAU OF STANDARDS	DR. D. BONNELL		
GE CORPORATE R&D	DR. C. BRAY	ULTRA-HIGH VACUUM VAPOR DEPOSITION: MOLECULAR BEAM EPITAXY	COULD LEAD TO A LARGE IMPROVEMENT IN THE QUALITY OF SEMI-CONDUCTOR LAYERS DEPOSITED. ADDITIONAL RESEARCH REQUIRED TO PROVE CONCEPT.
GE CORPORATE R&D	DR. C. NEUGEBAURER	ULTRA-HIGH VAPOR DEPOSITION	POSSIBLE APPLICATION FOR MULTI-LAYER VLSI DEVICES. REQUIRES R&D PROGRAM TO ESTABLISH POSSIBILITIES AND BENEFITS.
CENTER FOR REMOTE SENSING UNIVERSITY OF DELAWARE	DR. V. KLEMAS	REMOTE SENSING OF OCEANS & COASTAL FRONTS	COULD USE SPACE STATION AS MAN-TENDED OCEANIC OBSERVATORY. BENEFIT IS SOCIAL AND MAY NOT BE AMENABLE TO COMMERCIALIZATION.
GE CORPORATE R&D	DR. CHARLES BEAN	ISOENZYME SEPARATIONS USING LARGE PORE GEL ELECTROPHORESIS	IF APPLICATION FOR LARGER PORE GELS SPACE MANUFACTURING MAY BE REQUIRED. NOT A LIKELY CANDIDATE FOR A COMMERCIAL VENTURE.
GE CORPORATE R&D	DR. GINA WELCH	ISOENZYME SEPARATIONS USING LARGE PORE GEL ELECTROPHORESIS	MOST GELS CAN BE SEPARATED ON GROUND, HOWEVER, IF ENZYMES ARE IDENTIFIED WHICH ARE TOO LARGE FOR "AGAROSE" GEL ELECTROPHORESIS AND INSEPARABLE BY ISOELECTRIC FOCUSING THEN SPACE APPLICATION IS POSSIBLE.
BUREAU OF LAND MANAGEMENT DENVER, COLORADO	R. MARKER	DETECTION OF SURFACE MINING	WOULD USE SPACE STATION WHEN AVAILABLE. WOULD LIKE HIGH RESOLUTION AND MORE FREQUENT DATA THAN LANDSAT PROVIDES.

Table 2-1. User Contact Summary (Cont)

ORGANIZATION CONTACTED	USER KEY INDIVIDUAL	SUBJECT	RESULTS
POLYSCIENCES, INC. WARRINGTON, PA	DR. B. HALPERN	SEPARATION OF ISOENZYMES	SCIENTIFIC EXPERIMENTS ARE NEEDED TO DETERMINE THE ABILITY TO USE LARGE PORE GELS THAT COULD NOT BE SUPPORTED (STRUCTURALLY) IN ONE-G, IN BIOLOGICAL SEPARATIONS.
GE AIRCRAFT ENGINE DEPARTMENT	J. ERICSON	DIRECTIONAL SOLIDIFICATION USING SKIN TECHNOLOGY FOR TURBINE BLADES	MOST PROBLEMS HAVE BEEN OVERCOME IN THE MANUFACTURE OF TURBINE BLADES ON GROUND. INDUSTRIAL SPACE RESEARCH MIGHT LEAD TO THE DISCOVERY OF NEW TECHNIQUES THAT COULD BE APPLIED TO TERRESTRIAL MANUFACTURING.
YALE UNIVERSITY	PROF. PAUL NORDINE	CONTAINERLESS CHEMICAL REACTION STUDIES	POSSIBLE CANDIDATE FOR INDUSTRIAL RESEARCH.
MIT	PROF. M. FLEMINGS	UNDER COOLED SOLIDIFICATION STUDIES	POSSIBLE CANDIDATE FOR INDUSTRIAL RESEARCH.
LEHIGH UNIV.	DR. J. VANDERHOFF	PRECISION LATEX SPHERES	IF SUFFICIENT DEMAND FOR PRODUCT CAN BE FOUND, THE SPACE STATION APPLICATION IS POSSIBLE.
GE CR&D	DR. R. LAWTON	BIOMEDICAL MATERIALS	SPACE INDUSTRIAL RESEARCH COULD BE USED TO GAIN ADDITIONAL KNOWLEDGE ON BIOMEDICAL MATERIALS.
GE CR&D	R. WENTORF	POWDER METALLURGY	COULD USE HARD VACUUM OF SPACE TO REDUCE IMPURITIES AND FLUIDS ABSORBED IN THE PROCESS.
HARVARD UNIV.	DR. F. SPAEPEN	LARGE UNDER-COOLING OF MOLTEN MATERIALS	CANDIDATE INDUSTRIAL RESEARCH PROJECT THAT COULD PROVIDE VALUABLE SCIENTIFIC INFORMATION.
GE CR&D	DR. H. FINKBEINER	COMMERCIAL APPLICATIONS OF BIOPROCESSING IN SPACE	POSSIBLE CANDIDATES FOR INDUSTRIAL RESEARCH.
GE CR&D	O. LEBLANC	LIQUID THERMAL CONDUCTIVITY DATA WITHOUT CONVECTION	NO APPLICATION FOUND, FUTURE DISCUSSIONS COULD RESULT IN INDUSTRIAL RESEARCH.
M.A.N. WORKSTOFFTECHNIK MUNICH, FEDERAL REPUBLIC OF GERMANY	DR. H. SPRENGER	HIGH TEMPERATURE DIRECTIONAL SOLIDIFICATION	M.A.N. INTERESTED IN A COOPERATIVE VENTURE WITH GE DEVELOPING HIGH TEMPERATURE DIRECTIONAL SOLIDIFICATION PROCESS AND M.A.N. DEVELOPING FURTHER THEIR SKIN-CASTING TECHNIQUE. DISCUSSIONS WILL CONTINUE.

2.1 GE - RECOMMENDED INDUSTRIAL RESEARCH FACILITY

A positive step towards the establishment of broad industrial participation in the Space Station was suggested by the members of GE's Space Station Corporate Advisory Board (Please refer to Section 2.2 below). The concept is to provide an Industrial Research Facility on-board the Space Station, to permit commercial and research organizations to conduct materials research and development relevant to potential commercial products or services. It is envisioned that portions of this research will ultimately lead to commercial production in space, while other investigations will lead to knowledge that will enable or facilitate improved manufacturing processes on earth. This type of facility will make it possible for industrial concerns such as GE to conduct proprietary or open investigations in support of their current and projected product lines; this will include the determination of processing parameters which would enable them to make accurate economic assessments leading to decisions on commercialization. Initial portions of this research will be possible to be performed on-board Spacelab, as Materials Processing in Space (MPS) experiments.

The General Electric Company has initiated a Company-funded study by Corporate Research and Development (CR&D) to examine the R&D requirements that could be addressed through experimentation in such a facility. The study will be completed in June 1983 and the results will be summarized in a report with a set of recommendations to Mr. Allen Rosenberg, Vice President and General Manager of the Space Systems Division. Following is a brief description of the areas to be covered by the CR&D study.

The emphasis in the study will be in the area of materials research in which the benefits of a space environment; i.e., high vacuum and/or zero gravity, could lead to material with superior properties or to entirely new materials or combinations of materials that cannot be produced in a terrestrial environment. A second consideration will be in the potential ability to manufacture, refine or handle materials in space with less difficulty than it is now possible on earth and thus create a real economic payoff on products important to General Electric and industry in general.

The members of the study team are Dr. Gina Welch who is the technical contact looking into the areas of biological systems and electronic materials; Charles McFarland who is the technical contact responsible for examining areas of metallurgy and ceramics; and, Joseph Cargioli who will act as the program coordinator responsible for interfacing CRD with Space Systems Division program management. The study team has divided its work into three specific tasks covering a six month period.

The first task will involve brainstorming sessions with CRD personnel who are experts in various aspects of materials research. There will be at least five sessions chaired by our technical contacts involving leading CRD people in the following technical areas:

1. Biomaterials
2. Electronic Materials
3. Metallurgy
4. Ceramics

The first task will emphasize the short range implications of space experimentations, i.e., the potential scientific understanding that would be gained from materials behavior in high vacuum and zero gravity. This understanding will be used to develop the longer range (1990 and beyond) goals, those relating to useful space processing. The brainstorming sessions will be the idea gathering portion of the CRD program coupled with the library searches and discussions outside CRD. Some current ideas being considered are:

1. Larger pore gel electrophoresis for both DNA sequencing and chromosome karyotyping (inspection of cells to identify the chromosomes).
2. Tissue culture in emulsions for growing large quantities of eukaryotic cells (those cells pertaining to higher order plants and animals).
3. Incorporation of liquid immiscible phases into both metallic and non-metallic systems.
4. Containerless melting and metal delivery.
5. Die casting of titanium.

6. Improved melt homogeneity.
7. Radiation hardness of integrated circuits.
8. 3D electronic circuits.

The second task will be to evaluate from the lists of potentially feasible ideas deemed to be the most important, add value beyond that attainable on earth, and have the highest potential of survival beyond the experimental stage. The evaluation sessions will involve the study team technical contacts and their management whose job it will be to narrow the ideas down to a workable list of high feasibility experiments.

The third and final task of the CRD program will be to make recommendations to Space Systems Division Management based on the completed study. If the study does produce a recommendation to proceed, ground-based experiments and special handling will be discussed and special needs in equipment and personnel for the space experiment will be outlined. A final report will be submitted outlining in detail the results of the three tasks discussed in this program.

2.2 GENERAL ELECTRIC'S SPACE STATION CORPORATE ADVISORY BOARD

The Corporate Advisory Board (CAB) was formed to provide a broad corporate view of the study progress and results, and to establish perspective concerning investigational needs and commercial opportunities that will be able to be addressed by the Space Station. Historically, the CAB has a precedent in the GE Executive Panel established in the early 1970's and chaired by Mr. Dan Fink, to provide similar guidance in the study "Beneficial Uses of Space", which identified over 100 ideas for materials processes in space and analyzed the commercial potential of many of those ideas. The members of the CAB are shown on Table 2.2-1. The Board is chaired by Dr. William Sheeran, Manager of CR&D Liaison Operation. Dr. Sheeran's organization has liaison scientists representing the research needs of all the Sectors and Division groups in the General Electric Company. His intimate knowledge of the key research needs, people and organizations in GE has been invaluable in the chairmanship of this board.

The CAB has held three meetings held at the CR&D headquarters in Schenectady, NY, scheduled to precede important milestones in the study:

Meeting #1 30 September 1982, prior to mission definition

Meeting #2 29 October 1982, prior to the midterm briefing

Meeting #3 2 February 1983, prior to the final report and final briefings.

A fourth meeting is planned for June 1983 when the results of the aforementioned study of an Industrial Research Facility will be reviewed.

In addition to the idea of the Industrial Research Facility and the guidance and perspective in commercial use of space, the CAB has offered valuable suggestions for missions on the Space Station, for instance:

1. The use of ultra-high vacuum deposition (performed in a wake shield facility) to produce multi-layer silicon microcircuits. If this process could be performed in space, denser packages of integrated circuits could be achieved and many interconnections would be eliminated.
2. The possible use of electrophoretic separations of chromosome components in applications where the ultraresolution attainable in microgravity would be superior to the ground-based processes.

Table 2.2-1
General Electric
Space Station
Corporate Advisory Board Members

Board Members

Roy Anderson	Coolidge Fellow, Communication Technology and Systems Branch, Corporate Research and Development
Manuel Aven	R&D Manager, Materials Laboratories, Corporate Research and Development
Lonnie Edelheit	General Manager, Medical Systems Engineering Department, Medical Systems Business Operations
Bill Ehner	Manager, Motor Technology Operation, Motor Business Group
Guy Fougere	Staff Executive, Consumer Products Technology Operation, Consumer Products Sector
Bill Heiser	Manager, Technology Market Development, Aircraft Engine Business Group
Ray Shade	Manager, Advanced Technology Operation, Silicone Products Business Division
Bill Sheeran	Chairman of Advisory Board and Manager, Liaison Operation, Corporate Research and Development
Craig Tedmon	Staff Executive, Power Systems Technology Operation, Power Systems Sector
Kirby Vosburgh	Manager, Silicon Processing Branch, Corporate Research and Development

Ex Officio Members

Larry Alexander	Manager, Division Technology Planning, Space Systems Division
Jack Dickinson	Secretary, Corporate Advisory Board, Manager of General Electric Space Systems Division Utilization Office
Fritz Mezger	Manager, Technology Research and Planning, Space Systems Division
Jim Whitten	Liaison Scientist, Technical Systems Sector, Corporate Research and Development

3. The use of reflectance spectrometry with finer resolution than possible through Landsat, to aid in mineral exploration.
4. Use of vapor deposition for improving the life and energy density capabilities of X-Ray Tungsten Targets. (Previous concepts related to space processing of tungsten targets assumed the use of containerless melting and solidification of complete tungsten spheres, a process which was less weight-efficient than vapor deposition.)

The CAB has proven to be a very effective tool in the development of Space Station cognizance and constituency within the General Electric Company. As such, it may be a model for similar efforts in other industrial organizations which would benefit from space processing.

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SECTION 3
COMMERCIAL MISSIONS



SECTION 3 COMMERCIAL MISSIONS

3.1 MATERIALS PROCESSING

The reason for performing material processing in space is to take advantage of the unique properties of the space environment to do things that can not be done on earth. This may involve improvements to products traditionally produced on the ground, or it may involve totally new products that can be produced only in space. Most activities presently envisioned involve improvements to products currently produced on the ground.

Space provides two primary properties not available in earth based processes: long duration low gravity ("zero-g"), and hard vacuum with near-infinite pumping rates. Other properties such as unfiltered solar radiation and near-0° (absolute) heat sink temperature may also be of interest. Sustained low gravity is the property most often exploited in potential space processing activities.

Four representative space processing missions are presented in this section:

1. Production of X-ray targets. A vapor deposition process using high vacuum pumping rates and low gravity electromagnetic levitation produces improved tungsten crystal structure that can survive higher power densities associated with newer X-ray applications.
2. Production of biologicals. A continuous flow electrophoresis process using low gravity to benefit separation efficiency produces high purity substances for the treatment of various diseases.
3. Production of latex spheres. A chemical batch process using low gravity to benefit polymer reaction produces precision latex spares for medical research and calibration.
4. Production of Isoenzymes. A large pore gel electrophoresis batch process using low gravity to benefit separation accuracy produces high purity isoenzymes for medical diagnostic kits.

3.1.1 SPACE PRODUCTION OF TUNGSTEN X-RAY TARGETS

Introduction

The technical and commercial prospects for a business venture based on the preparation of tungsten x-ray tube targets with improved service properties in

a space-based microgravity facility has been re-examined. Such a possibility was studied in the earlier General Electric (GE) Beneficial Uses of Space (BUS) investigations where it was selected as one of four example processes in the Phase III Final Report (Nov. 30, 1975). Recent visits to the GE Medical Systems Division, where x-ray tubes are manufactured, and to the Corporate Research and Development Center, which does basic metallurgical research to support this work, indicates that improvements possible by the exploitation of the microgravity environment are still of interest. The earlier ideas of forming tungsten of improved crystal structure by undercooled solidification have now been extended to include possibilities for vapor deposition from molten tungsten levitated at high superheat in the microgravity environment.

A significant amount of work has been done in the terrestrial laboratory at GE using electromagnetic levitation techniques to suspend molten tungsten in a vacuum. The production of 1 cm single crystals by allowing the suspended material to solidify by radiative cooling after cessation of electron beam melting has been reported in the literature, but practical yields cannot be achieved because of levitation instabilities which occur because of the high tungsten density and outgassing at the high melting temperature. It is believed that practicable single crystal production rates could be achieved by levitation in a microgravity environment. This environment would also allow possible production of fine grained or vapor deposited material by achieving larger undercoolings or higher superheats than possible terrestrially. Present limitations in x-ray target segments are believed largely associated with the necessity of using powder metallurgy techniques with the associated contamination and poor intergranular bonding.

Market Analysis

The detailed market forecast carried out in the BUS study is still assumed valid. This shows a world demand for 160,000 x-ray target segments by the year 1992. A new requirement for target technology is the ability to survive the higher power densities associated with Computer Aided Tomography (CAT) applications. Success in achieving a long-life x-ray tube which provided the needed high resolution could form the basis for a reasonable assumption of a 50% world market penetration with a target selling price of \$500. It should be mentioned that GE is the sole U.S. manufacturer of x-ray targets, which has led to regulation of this business.

Mission Description

The overall x-ray target production process is summarized in Figure 3.1.1-1. Materials prepared on the ground include tungsten spheres that serve as sources during the in-space vapor deposition process and molybdenum substrates that receive a coating of high purity tungsten. An alternative in-space process would be to grow high purity tungsten crystals, in which case the molybdenum substrates would not be used. After in-space processing the high purity tungsten target segments are machined and bonded to molybdenum target wheels, which are subsequently incorporated within large vacuum tubes that produce x-rays in medical and industrial implications. A typical target wheel is roughly 3 inches in diameter and has a tungsten target area that forms a 1/2 inch ring near the circumference of one of its faces.

The in-space process would consist of electromagnetic levitation in a vacuum (less than 10^{-5} torr) of tungsten spheres of several cm diameter (terrestrial levitation is restricted to diameter of about 1 cm). The material is melted using an electron beam after heating to the point of thermionic emission by induction. A conceptual processing facility is illustrated in Figure 3.1.1-2. Two processes are available for yielding tungsten of potentially better metallurgical properties than the present powder metallurgy product: undercooled solidification, or vapor deposition on a molybdenum substrate by superheating the melt. The latter possibility is particularly attractive because of the minimization of tungsten scrap and post processing machining costs, as well as the possibility of utilizing thinner tungsten layers.

A pure tungsten layer of at least 6 mils is needed for most x-ray targets. This would typically require 20 minutes to build up using the vacuum vapor deposition process. Processing sufficient target segments to build 80,000 targets per year requires 12 hours per day of active production. This could be accomplished with two 8-hour cycles per day, each consisting of 6 hours of active production and 2 hours of loading, unloading, start up and shut down.

Requirements

The required space borne equipment has been described in the BUS final report, Book 3. Table 3.1.1-1, taken from that report, shows a description and weight breakdown by equipment components for processing of 1 and 5 cm diameter tungsten spheres. We have found that the economics of the vapor deposition

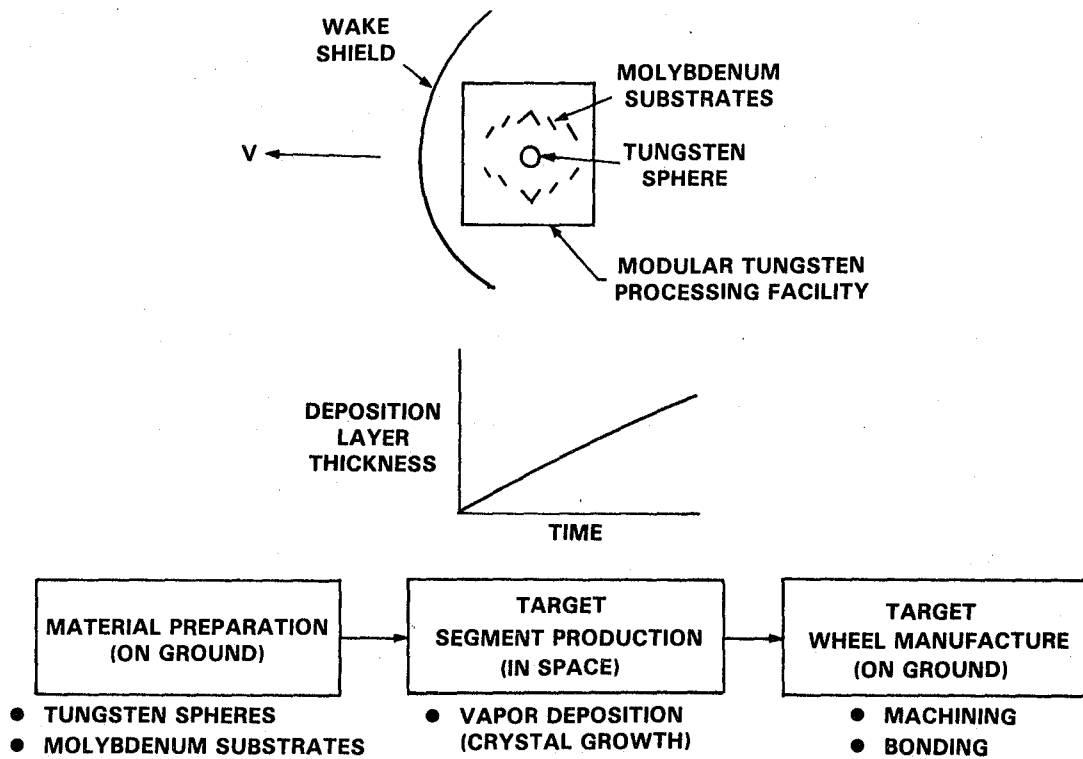


Figure 3.1.1-1. Tungsten X-Ray Target Production Process

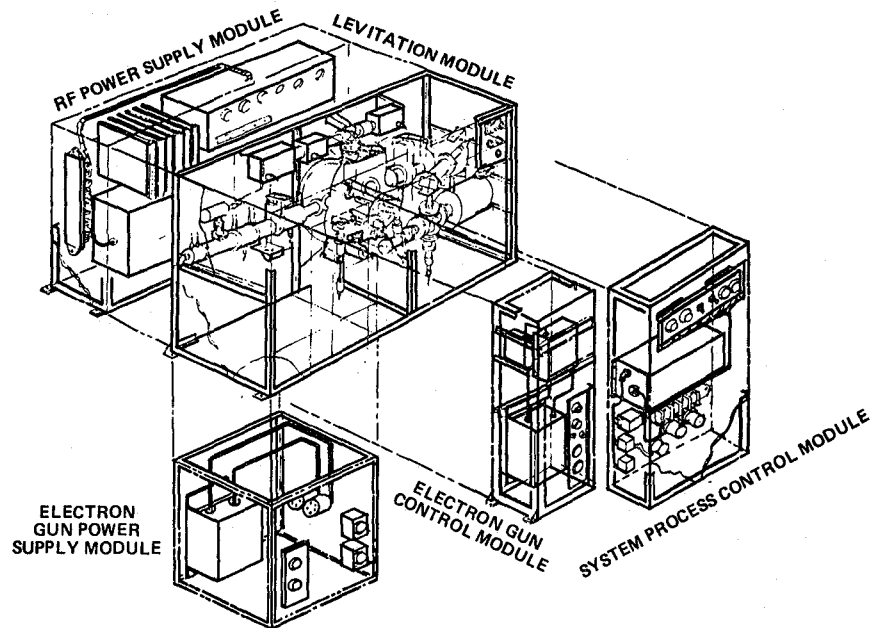


Figure 3.1.1-2. Modular Tungsten Processing Facility

Table 3.1.1-1. Modular Tungsten Processing Facility Equipment

	EXPERIMENT VERSION (1 CM. DIAMETER SPECIMENS)		PRODUCTION VERSION (5 CM. DIAMETER SPECIMENS)	
	LB.	KG.	LB.	KG.
CHAMBER & STRUCTURE	(143)	65	(143)	65
SAMPLE/CHARGE HANDLING	(145)	65.9	(300)	136.4
GATE VALVES	(94)	42.7	(94)	42.7
VENTING SYSTEM	(10)	4.5	(10)	4.5
GAS SUPPLY & PLUMBING	(20)	9.1	(10)	9.1
ION GAUGE & CONTROL	(20)	9.1	(20)	9.1
PROCESS CONTROLLER AND ELECTRONICS	(58)	26.4	(100)	45.5
ELECTRON BEAM GUN & POWER SUPPLY	(65)	29.5	(100)	45.5
ELECTRON BEAM POWER CONDITIONER	(100)	45.5	(150)	68.5
OPTICAL PYROMETER	(25)	11.4	(25)	11.4
MASS SPECTROMETER	(12)	5.4	(12)	5.4
CAMERA & LAMP	(13)	5.9	—	—
TV MONITOR	—	—	(15)	6.8
PROCESS RECORDER	(8)	3.6	(8)	3.6
RF POSITIONING COIL UNIT	(7)	3.2	(20)	9.1
COIL COOLING SYSTEM	(50)	22.7	(100)	45.4
RF POWER CONDITIONER	(30)	13.6	(100)	45.5
CABLING AND TERMINALS	(10)	4.5	(20)	9.1
	(810)	368	(1237)	561.9
VACUUM SYSTEM SUPPORT	(250)	113.6	(250)	113.6
10% CONTINGENCY	(106)	48.2	(149)	67.6
TOTAL	(1166)	529.8	(1636)	743.1

process appears more favorable for spheres of 1.84 cm diameter; nevertheless, we have doubled the estimated weight for the space production facility to 1500 kg in order to provide a more conservative design which exploits the much greater in-orbit residence time made possible by the Space Station. With the addition of 500 kg for a wake shield, total weight launched to orbit is 2000 kg.

Aside from on-board microprocessing of data for process control, a once per day data dump to earth consisting mainly of 1 megabit of specimen image information should be provided. In the initial phases of operation, a single astronaut/technician would devote 8 hours per day to supervising the automated facility operation, loading and unloading it, and insuring safety of operation. Later, required manned attendance could be considerably reduced. Monthly maintenance and logistics activities would require 16 man hours. A total of 2220 kg per year of tungsten, molybdenum substrate, and shipping containers would be brought up from earth and returned. Processed material should be returned to earth at least once per month. About 120 kg of expendable inert gas per year would also be required. These requirements have been summarized in the Payload Element summary sheets. At this time it is believed that a single facility would have an in-orbit useful lifetime of approximately three years, limited by obsolescence. The most significant facility requirement is perhaps the rather large in-orbit power requirement, which can be reduced to 15 kw as compared with as much as 50 by use of a smaller specimen (1.84 cm) at 200° superheat.

Benefits

A comparison of costs for three different implementation approaches is shown in Figure 3.1.1-3. The computations are summarized in Table 3.1.1-2. The results show that the cost of performing this mission using the Space Station is 2/3 the cost of a free flyer serviced by the STS. The cost of implementing this mission using Spacelab is an order of magnitude higher due to the large number of launches required.

The market value of an 80,000 target per year production is summarized in Table 3.1.1-3. Mission costs are for Space Station implementation. Other costs include ground manufacturing and administration.

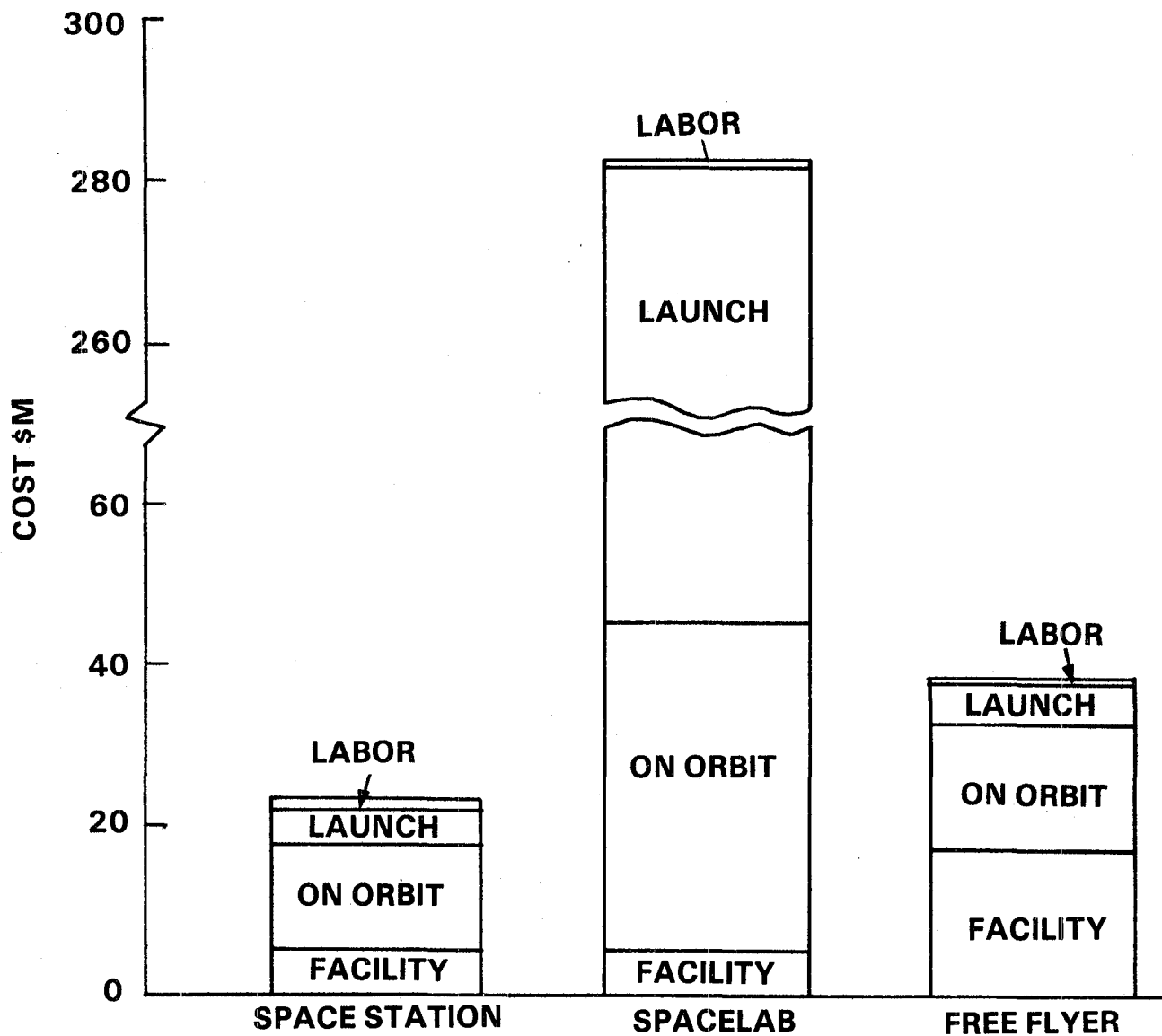


Figure 3.1.1-3. Space Production of X-Ray Targets Mission Comparison

Table 3.1.1-2. Space Production of Tungsten X-Ray Targets
(Annual Costs)

COST CATEGORY		SPACE STATION		SPACELAB/STS		FREE FLYER	
LABOR:	TECHNICIAN (\$10.2 M/MAN YR)	.07 MAN YEAR	0.7M	.07 MAN YEAR	0.7M	0.01 MAN YEAR	0.1M
	GROUND CREW (\$1500/MAN WK)	3 HEADS	0.2M	3 HEADS	0.2M	3 HEADS	0.2M
LAUNCH:	PAYLOAD LOGISTICS SUPP. (\$84.3 M/LAUNCH)	.07 P/L/5 YRS .04 P/L/YR	1.2M 3.4M	.07 P/L X 40 N/A	236 M —	.1 P/L /5 YRS .04 P/L/YR	1.7M 3.4M
	RENDEZVOUS COST (\$0.88 M EACH)	.04 X 1	0	N/A	—	0.4 X 1	0
ON ORBIT:	ENERGY (\$1M/KW-YR)	15 KW X 5/6 YR	12.5 M	15 KW X 4/5 YR	12 M	15 KW X 5/6 YR	12.5M
	LOITER DAYS (\$0.66 M EACH)	N/A	—	N/A	—	5/YR	3.3M
	SPACELAB FLT. (\$10 M EACH)	N/A	—	.07 P/L X 40	28 M	N/A	—
EQUIPMENT DDT & E/P		SEMI AUTO (PER 5 YR)	5 M	SEMI AUTO (PER 5 YR)	5 M	AUTOMATED (PER 5 YR)	7 M
SPACECRAFT DDT & E/P		N/A	—	N/A	—	DEDICATED (PER 5 YR)	10 M
TOTAL COST		23.0 M		281.9 M		38.2 M	

Table 3.1.1-3. X-Ray Target Production Annual Market Value

SALES **\$40.0 M**

MISSION COSTS **23.0 M**

OTHER COSTS (GROUND MANUFACTURING, ETC.) **8.0 M**

POTENTIAL PROFIT **9.0 M**

3.1.2 COMMERCIAL PRODUCTION OF BIOLOGICALS

Market Analysis

The market for biological products that potentially could benefit from processing in microgravity is very significant. These products include not only diagnostic substances but also therapeutic ones, typical of which are urokinase, produced from kidney cells and used in the treatment of blood clots; somatotroph, used to treat growth hormone deficiencies; and Beta cells used in the treatment of diabetes. The latter, for instance, is a common chronic disease affecting millions of people worldwide. In the United States alone, approximately 5 million people are afflicted with this disease. Over \$12 billion is spent in the United States for the cure of diabetes, including drug therapy (primary the administration of insulin), hospital care, home care, laboratory evaluations and health education. It is estimated, considering this spectrum of health care activities, that the full-scale production and administration of Beta cells for treatment of a large portion of the diabetic population would be a multi-hundred million dollar industry, worldwide. Recent advances in the growth of Beta cells in cultures look promising; however, the problem of rejection by the body needs to be solved, possibly through improved purity of the cells. Continued advances in the production of urokinase and somatotroph also promise to be translated into more available, improved products to the users.

Our discussions with researchers in Wyeth Laboratories and GE Corporate Research and Development helped to place the spaceborne electrophoretic separations within the context of recent and projected developments in this rapidly advancing scientific/industrial field. It was pointed out that there are several new bioprocessing techniques for the production of pharmaceuticals which would compete with electrophoresis. Notable among these techniques are DNA Splicing, Fluorescence Activated Cell Sorting (FACS), and Monoclonal Antibodies (MAB's). The latter, for instance, only represented a market of \$15 million in 1982, but is estimated to grow to \$5 billion by 1992. If spaceborne electrophoresis is proven to yield a superior product or a less expensive one, it could capture a large portion of that market, within the time-frame of the Space Station. Additional laboratory and space research is needed to identify and assess this portion of the market in selected areas where continuous flow electrophoresis is applicable. The specific characteristics of separations in microgravity and their performance and cost

advantage over other competing techniques will thus be determined. Most of this space experimentation will be possible on-board Spacelab, prior to potential large-scale production on-board the Space Station.

For planning purposes, we have estimated that the initial phases of full-scale production in space will produce relatively modest amounts of biologicals, in the order of 120 kg the undiluted yield per year. These are based on producing biologicals with high economic leverage where minute amounts of the substance will be used in each diagnostic or therapeutic kit.

Mission Description

The basic production process is illustrated schematically in Figure 3.1.2-1. The principal characteristic of the space environment that is utilized in this mission is reduced gravity, which reduces thermal driven convection. The continuous flow electrophoresis process consists of performing separations (or purification) of biologicals by exploiting the variation in mobility of its constituents (e.g., pure biological, impurities) due to the application of an electric field across the cell containing the biological. Since the precision and resolution of these separations depend on the unperturbed deflection of the flow due to its susceptibility to the electric field, it is important to minimize the disturbing effects of thermal driven convection. In a microgravity environment in space, the thermally driven convection becomes negligible and therefore potentially, the electrophoretic separations will be significantly improved.

The equipment required to perform this mission will consist of the electrophoretic separation cell, fluid storage vessels and auxiliary operation and control apparatus. Figure 3.1.2-2 shows a typical conceptual arrangement for the incorporation of the equipment within a pressurized module which permits operation. There are three equipment racks (patterned after those used by Spacelab). The center rack houses the electrophoretic cell, electronic controls for astronaut interface, and the separation-fraction collection vessels. The rack on the left carries a microprocessor (for process control and safety data management), a freezer, and buffer fluid storage, while the third rack would contain the unprocessed biologicals, a centrifuge (if required in some of the processes) and the thermal control system for the unit.

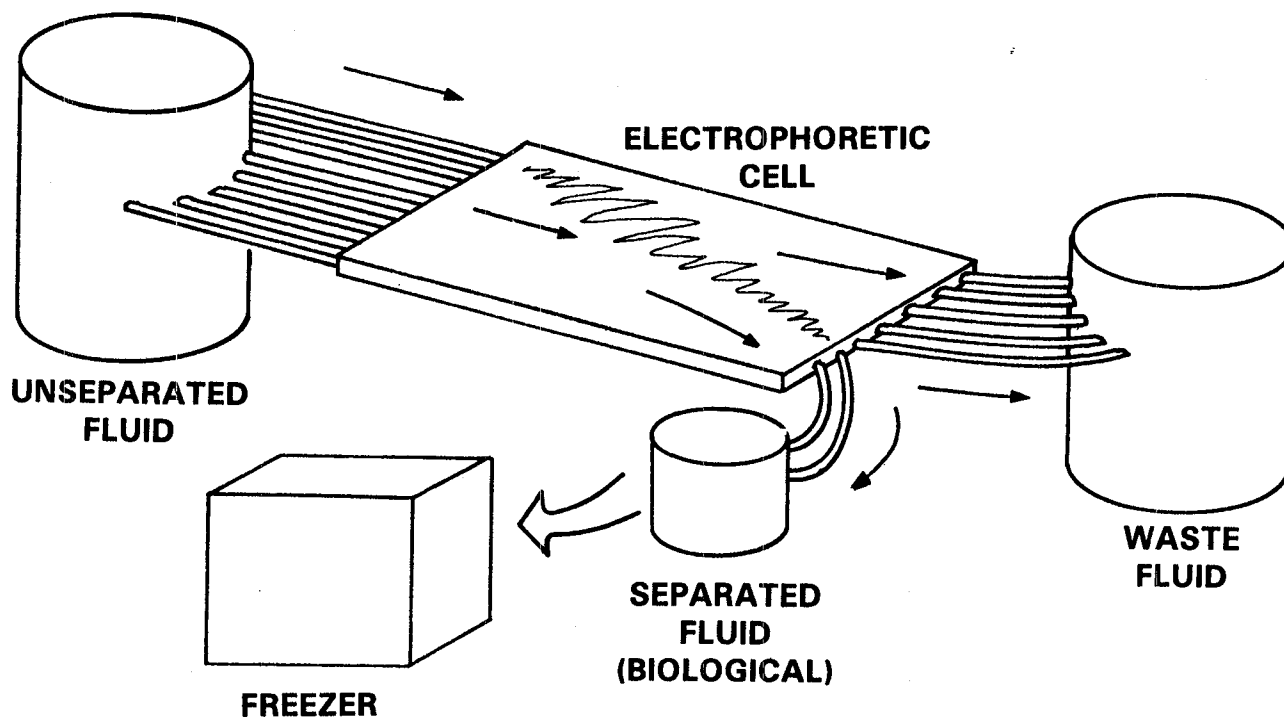


Figure 3.1.2-1. Production of Biologicals by Continuous Flow Electrophoresis



Figure 3.1.2-2. Biologicals Production Facility

The role of the crew in this mission would be the loading and unloading of biologicals during the logistic cycles, control and monitoring of the biological separation cycles, maintenance/repair, and modification of the process parameters if the conditions warrant it. In full production, a dedicated technician could be devoted to this mission during a 10-12 hour period per day (with automated sequences being scheduled during non-attended hours of the day. A typical production run would be 24 hours in duration.

Requirements

Crew involvement in this mission will require a technician who is thoroughly trained in the operation and maintenance of the electrophoretic apparatus. Although a scientist is not needed for the mission, the technician should be well versed in the biological aspects of the separations that are to be performed.

The nominal weight of the mission equipment is approximately 410 kg. Every three years the equipment is replaced or refurbished as a maintenance procedure, to expand its capabilities (as required) and take advantage of improvements that are made possible by the intervening technological advance. The average operating power requirement is 700 watts, and standby power is approximately 250 watts.

The nominal logistics cycle for delivery of new material and return of products is 30 days. The new material transported up is 250 kg of dilute unseparated fluid per cycle, or 3000 kg per year. The products transported down are 100 kg of dilute biological material plus 150 kg of waste per cycle, or 1200 kg and 1800 kg respectively per year. The 1200 kg of dilute biologicals is subsequently concentrated to 120 kg of undiluted product on the ground.

Benefits Analysis

The estimate of the value of space-produced biologicals will require two intermediate steps, in accordance with the previous discussion under "Market Analysis": (1) laboratory and space experimentation and analysis to obtain a better scientific understanding of the characteristics of electrophoretic separations of various classes of biological substance; and (2) a detailed comparison of the improved properties of these separations with the products that are possible and those that are projected using new processing techniques

such as DNA Splicing, Fluorescence Activated Cell Sorting (FACS), and Monodonal Antibodies (MAB's). Once the unique products that show an advantage from space processing have been identified, the actual benefits can be easily assessed.

A comparison of the costs associated with three different implementation techniques is shown in Figure 3.1.2-3. The computations are summarized in Table 3.1.2-1. The results show that the cost of performing this mission can be reduced by approximately 20% by using the Space Station, compared with Spacelab. The cost of implementing the mission is almost doubled by using a dedicated free-flyer.

3.1.3 PRODUCTION OF LATEX SPHERES

Introduction

The Monodisperse Latex project is an example of government/industry/university cooperation to successfully bring about a beneficial outcome. During the study "Space Processing P/L Equipment", a number of potential projects were identified as having promise for commercial application. One of these was the project suggested by Dr. J. Vanderhof of Lehigh University. The General Electric Company worked with Dr. Vanderhof in specifying requirements for the instrument package.

Market Analysis

The objective of the mission is to produce latex spheres in 2 to 40 microns with a very narrow 1% distribution. Such narrow distributions were unobtainable on earth due to the effect of gravity on the chemical mix during polymerization. Initial work was carried out by GE discretionary resources while Lehigh University received NASA funds for research. Using support from NASA Headquarters as well as from the Marshall Space Flight Center, the project was accepted by NASA as one having the earliest possible commercial application for the use of space. The support came from the realization by Headquarters and MSFC that the polymer spheres produced would be of significant value in medical research and calibration of sensitive medical instrumentation. One immediate example is the calibration of blood sampling equipment at hospitals and diagnostic laboratories - blood platelets are on the order of 7 microns in size. Cancer research would also benefit - determination of pore size is important here. A preliminary assessment by

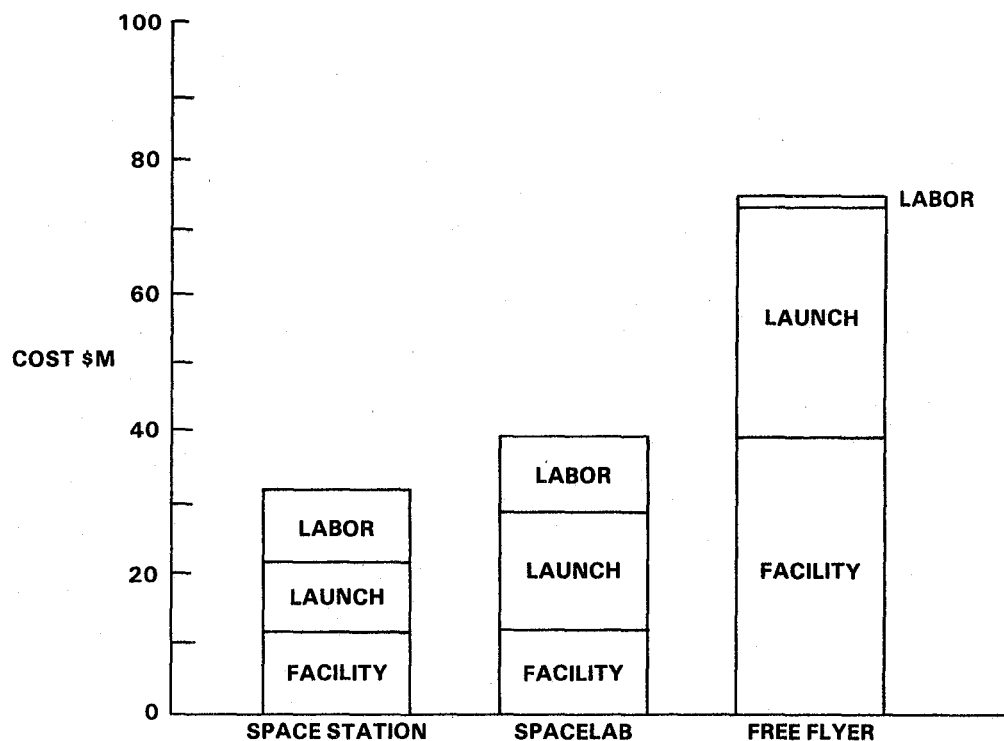


Figure 3.1.2-3. Commercial Production of Biologicals Mission Comparison (Annual Cycle)

Table 3.1.2-1. Commercial Production of Biologicals Cost Comparison (Annual Cycle)

COST CATEGORY		SPACE STATION		SPACELAB/STS		DEDICATED FREE FLYER	
LABOR:	TECHNICIAN (\$10.2 M/MAN YR)	1 MAN	10.2 M	1 MAN	10.2 M	1 MAN WK	0.2 M
	GROUND CREW (\$1500/MAN WK)	2 MEN	0.2 M	2 MEN	0.2 M	4	0.3 M
LAUNCH:	PAYLOAD (\$84.3 M/LAUNCH)	0.1 SHUTTLE P/L	8.4 M	0.1 SHUTTLE P/L X 6 LAUNCHES	17.2 M	0.5 SHUTTLE P/L	14.0 M
	RENDEZVOUS COST (\$0.88 M EACH)	3 REND.	0.9 M	N/A	—	12 REND./YR	10.6 M
ON ORBIT:	LOITERING (\$0.66 M EACH)	N/A	—	N/A	—	12 CYCLES	7.9 M
EQUIPMENT DDT & E		SEMI AUTO	11.7 M	SEMI AUTO	11.7 M	AUTOMATED	17.9 M
SPACECRAFT DDT & E						DEDICATED	23.3 M
TOTAL COST		31.4 M		39.3 M		74.2 M	

NASA, Dr. Vanderhof and GE indicated a substantial potential market for these sizes of latex spheres. Interest was also expressed by various chemical concerns in marketing the produce of these experiments. (Dow Chemical, and Polysciences). With this alignment, NASA has proceeded with preliminary experiments which have flown successfully on STS3 and STS4 (Columbia test flights).

A number of criteria can be used in determining the benefit of a project such as the Monodisperse Latex to mankind. These fall in the area of economic, social and increase in performance. The General Electric Company has performed some very preliminary benefit analysis relative to the Monodisperse Latex. From the social aspect, it is clear that a product of this kind has significant social impact should it serve to aid in the cure of diseases as cancer. As research aids or medicine carriers which can pinpoint very specifically the application of the necessary antibiotic, the impact of the spheres is readily discernible. Economically the near term presents a challenge since initial demand and usage are marginal when compared to currently available but inferior products used in like circumstances. Figure 3.1.3-1 shows the results of a pricing analysis for various discounted cash rate of returns used by industry. Clearly the cost will drop and hence the price, as large quantities are produced. However, the demand has to be there to ensure the validity of the results. The initial quantities will operate (near term) in the Case 1 and Case 2 areas. Future demand will permit lowering the price at the same time that a Space Station permits large batch production.

Mission Description

The Monodisperse Latex Spheres are produced by introducing a seed which is sequentially grown to larger sizes in a batch process. This approach is satisfactory for initial experimentation. A polymer reaction takes approximately 24 hours to complete, hence a sequential growth from 2 microns to 7 microns would require four days of processing. The basic production process is illustrated in Figure 3.1.3-2. Figure 3.1.3-3 shows a near term concept for producing batch quantities of up to a liter. The initial demand could be satisfied by proliferation of Space Shuttle flights carrying this equipment into orbit. Near term demand would probably require one or two such Shuttle flights per year. However, applications of this substance could be expected to proliferate as its uses are evaluated by the chemical community.

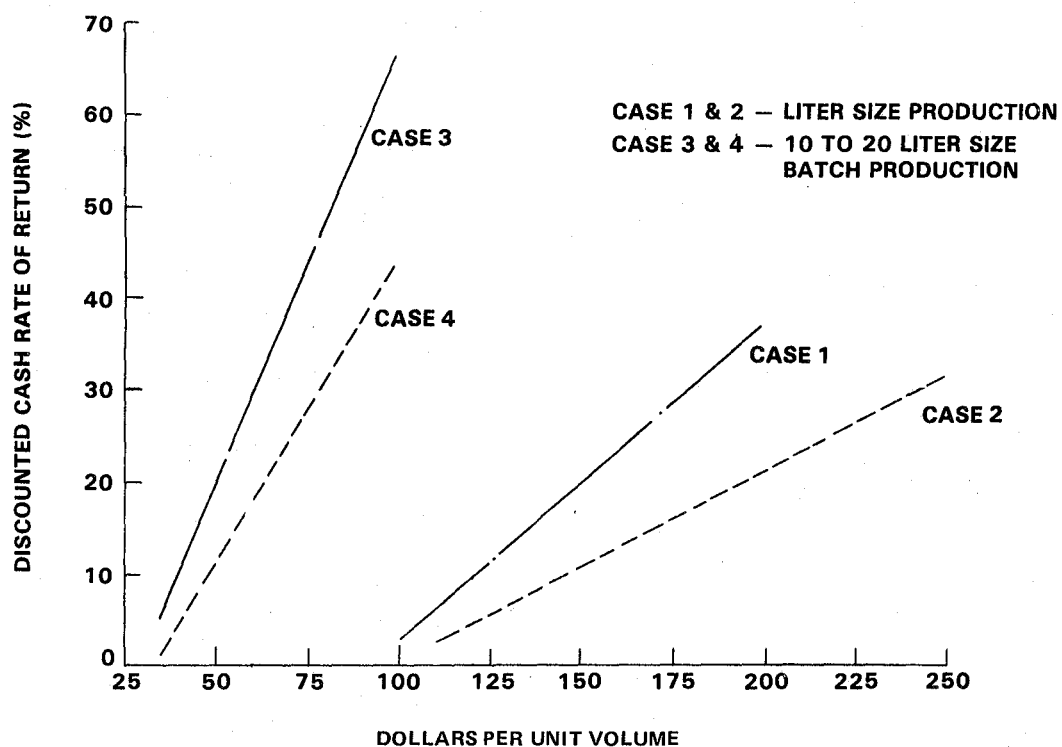


Figure 3.1.3-1. Results of Economic Analyses for Latex Spheres

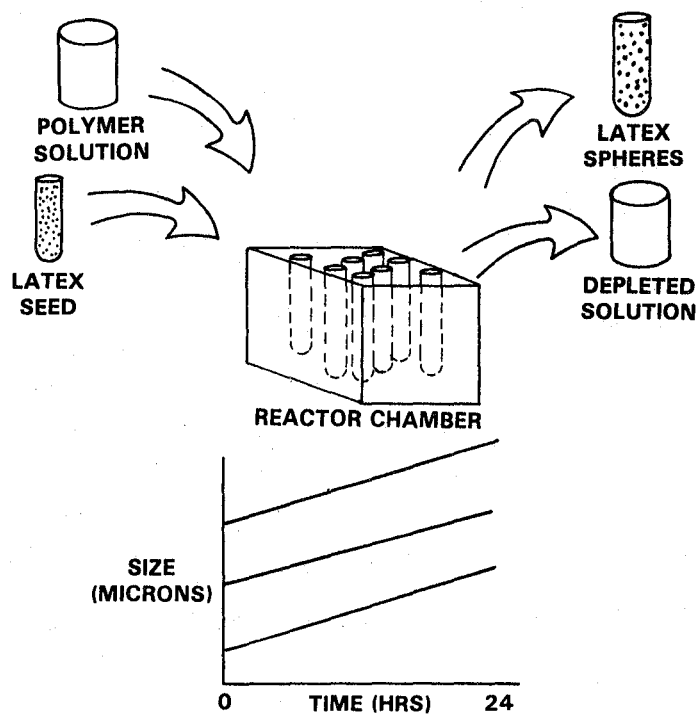


Figure 3.1.3-2. Monodisperse Latex Spheres Production Process

Far term projections can be expected to approach current demand for smaller (below 2 microns) sized latex particles. This demand requires the production in 20 liter batches. This would require a permanent Space Station facility which would use the Space Shuttle as a carrier of the product back to earth and to refurbish the consumables used in the polymerization reaction. (See Figure 3.2.3-4). The consumables would be transferred into the factory while the product in a semi-dried and therefore compact condition would be retrieved by the Shuttle for distribution to users on earth aboard compact holding tanks aboard the Shuttle.

Requirements

A number of 20 liter containers would be required to effectively perform the polymerization in a Space Station factory. Crew requirements are minimal since the process would be automated. A single crew member serving in a monitoring role would be sufficient. Power requirements are scalable. The larger quantities proposed here would require less power since the reaction is exothermic. However, since cooling may then be required, the overall power requirement for the process would be 20 kilowatts for 20 to 30 minutes followed by a maintenance level of 2 kilowatts for a reaction lasting up to 20 hours. Since up to eight reactions may be necessary to perform the batch production process, the power requirements would hold for an eight day duration. Crew time on the other hand is required only during loading of chemicals and transfer of reactants between containers, a process that should take at most one hour per operation. Therefore the crew time needed in actual active operation is eight hours, spread over an eight-day period. The Shuttle is used for supplying the chemical reagents to the Station and for carrying the product back to earth.

Benefit Analysis

The three alternative implementation modes are: Space Station, Shuttle payload or free-flyer. The comparative cost of performing the mission in these modes is shown in Figure 3.1.3-5. The computations are summarized in Table 3.1.3-1. There are some savings by performing the mission in the Space Station. However, these savings become appreciable only if the production rate is several times larger than the 20 liter capacity sized for pilot-plant demonstration on board the Shuttle.

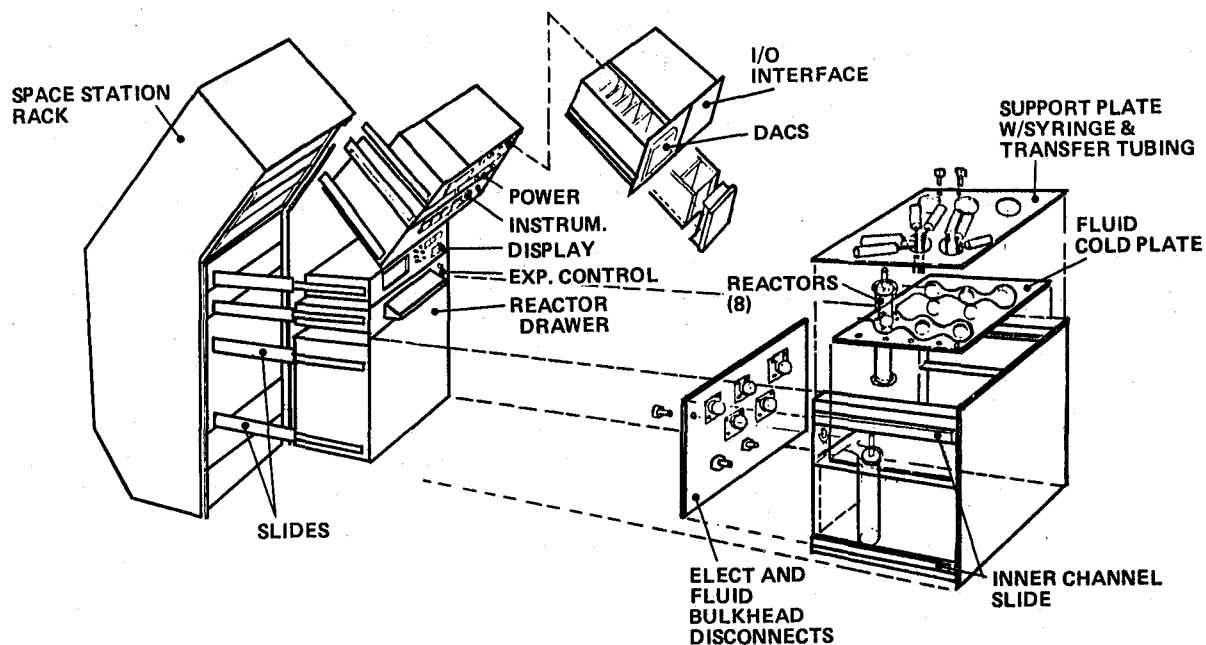


Figure 3.1.3-3. PLR System Intermediate Factory (Near Term)

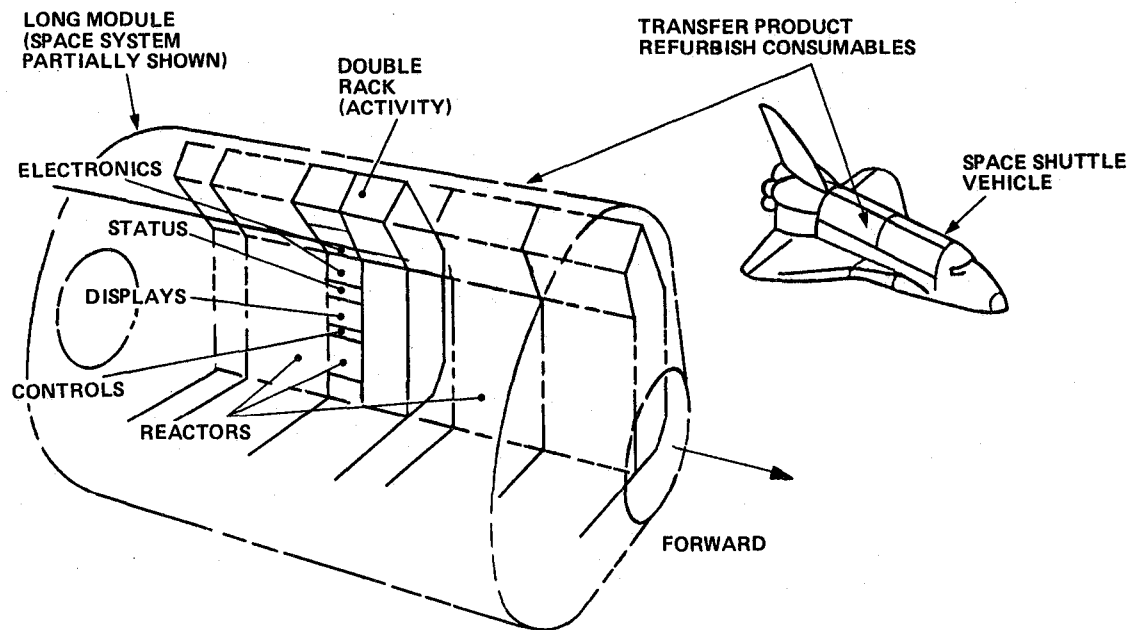


Figure 3.1.3-4. Space Station Module Preliminary Concept

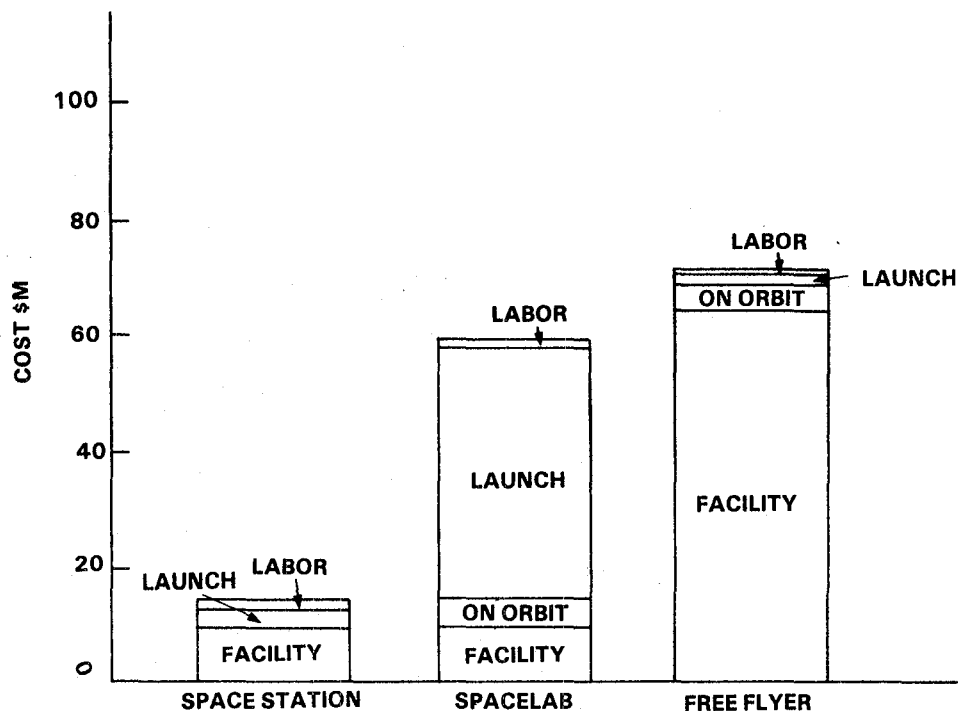


Figure 3.1.3-5. Production of Latex Spheres Mission Comparison

Table 3.1.3-1. Production of Latex Spheres (Annual Costs)

COST CATEGORY		SPACE STATION		SPACELAB/STS		FREE FLYER	
LABOR:	TECHNICIAN (\$10.2 M/MAN YR)	0.2 MAN YEAR	2.0M	0.2 MAN YEAR	2.0 M	0.01 MAN YEAR	0.1M
	GROUND CREW (\$1500/MAN WK)	3 HEADS	0.2M	3 HEADS	0.2 M	3 HEADS	0.2M
LAUNCH:	PAYLOAD LOGISTICS SUPP. (\$84.3 M/LAUNCH)	.07 P/L/5 YRS .01 P/L	1.2M 0.8M	.01 X 50 N/A	42.2 M —	.07 P/L/5 YRS .01 P/L	1.2M 0.8M
	RENDEZVOUS COST (\$0.88 M EACH)	.01 X 1	0	N/A	—	.01 X 1	0
ON ORBIT:	LOITER DAYS (\$0.66 M EACH)	N/A	—	N/A	—	5	3.3M
	SPACELAB FLT. (\$10 M EACH)	N/A	—	.01 X 50	5.0 M	N/A	—
EQUIPMENT DDT & E/P		SEMI AUTO	10.0 M	SEMI AUTO	10.0 M	AUTOMATED	15.0M
SPACECRAFT DDT & E/P		N/A	—	N/A	—	DEDICATED	50.0 M
TOTAL COST		14.2 M		59.4 M		70.6 M	

3.1.4 PRODUCTION OF ISOENZYMES

Introduction

There are many pharmacological substances such as enzymes, isoenzymes, hormones, etc. which are difficult to isolate from similar substances with sufficient resolution to provide significant quantities for medical use. For many substances with similar electrophoretic mobilities, the most successful ground-based technique for isolation is conventional small pore gel electrophoresis. However, these separations generally do not provide sufficient resolution with large scale yield of the desired product. In zero-g, using large pore gels which cannot be maintained in one-g, increased resolving power of the separation while maintaining low ohms heating and low electrical potential, is expected to provide reasonable yields of high specificity product. The process is illustrated schematically in Figure 3.1.4-1.

A typical example of an electrophoretic separations technology mission is the Large Pore Gel Electrophoretic Separation of Isoenzymes (antigens) used for the production of medical diagnostic kits. The overall production cycle is outlined in Figure 3.1.4-2.

Market Analysis

The production of isoenzymes in space would open up a market for diagnostic kits that could be used by physicians and clinics. The kit would contain antibodies, which are produced by the isoenzymes, to permit the diagnosis of many diagnosis of many diseases. Isoenzymes of most immediate interest would be substances such as glycogen phosphorylase and creatine kinase.

The isoenzymes separation system envisioned for Space Station would be flown in three phases: pilot plant, small scale production, and full scale production. At the start of full scale production, annual sales of 5 million kits are assumed. Based on market data developed in the BUS study (Ref. 1), the price per kit would be \$16.50 in 1984 dollars. Annual market potential is as follows:

Pilot Plant: 1.25 million kits at \$20.6 M sales.

Small Scale Production: 2.5 million kits at \$41.25 M sales.

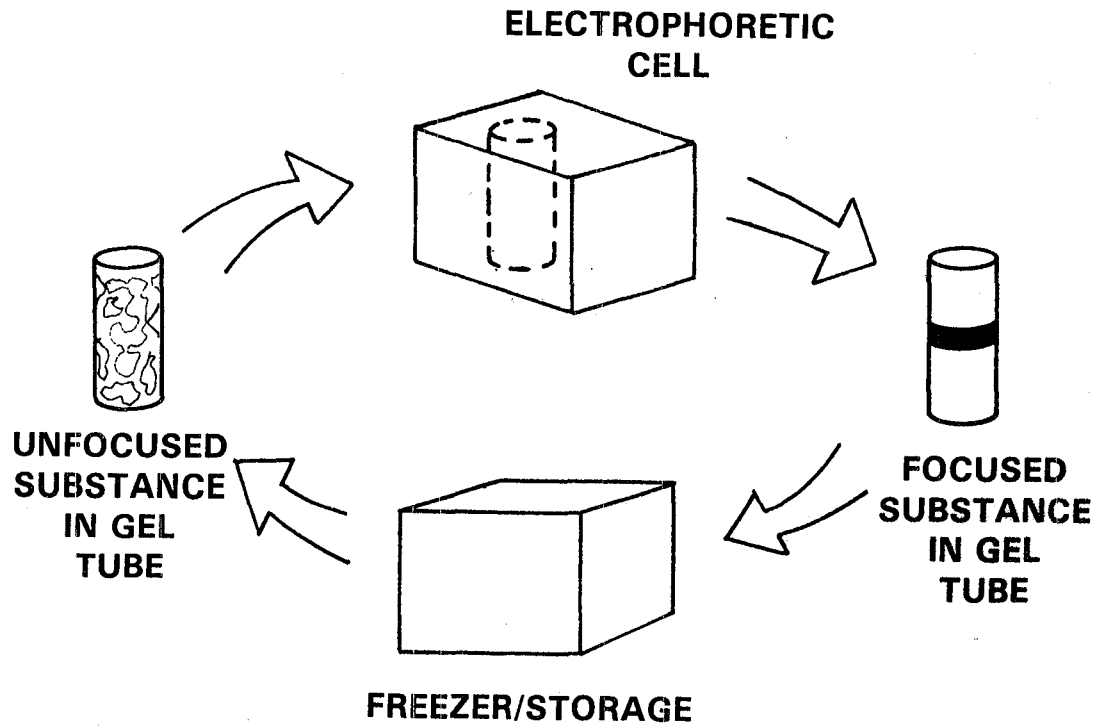


Figure 3.1.4-1. Separation of Isoenzymes by Large Pore Gel Electrophoresis

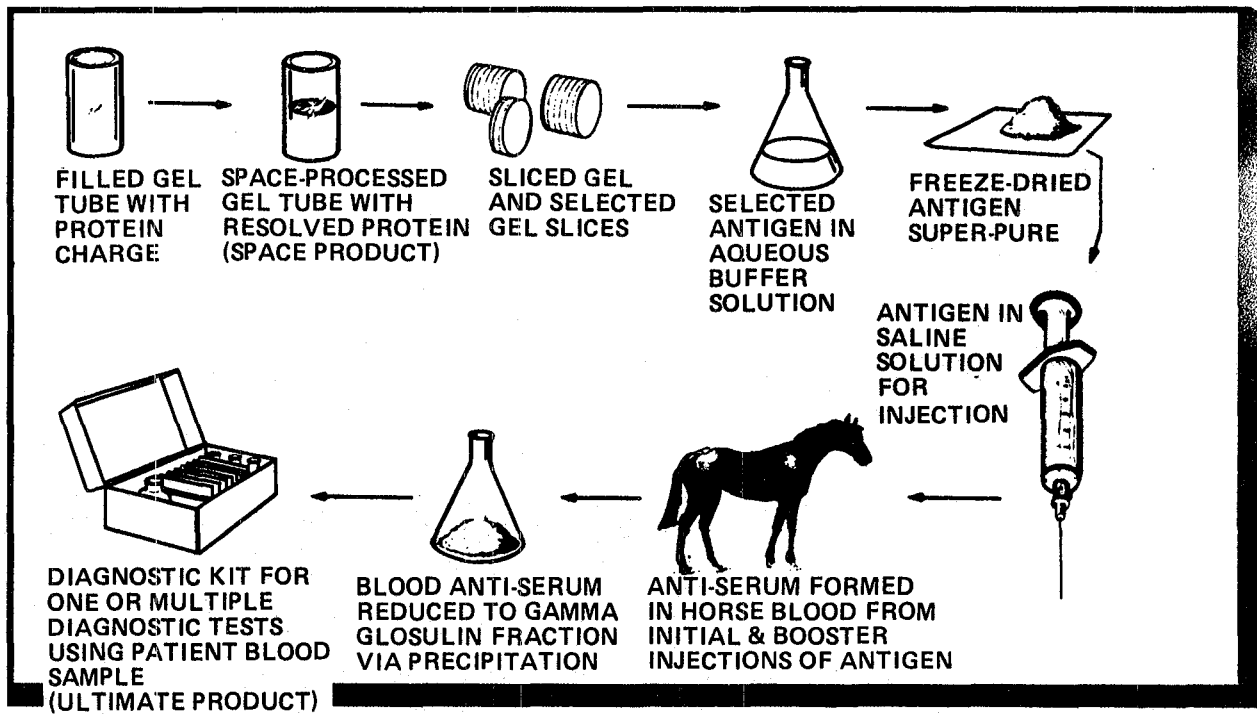


Figure 3.1.4-2. Isoenzymes Overall Processing Cycle

Full Scale Production: 5 million kits at \$82.5 M sales, increasing to 12.5 million kits at \$206 M sales by the year 2000.

Mission Description

The objective of the mission is to provide a facility with sufficient resolution and throughput for the commercial production of isoenzymes. The Space Station provides a shirtsleeve environment where the operator loads raw material, monitors the processing, and removes the products on a daily basis.

Initially, shuttle sortie missions will be required to verify the concept of large pore gel electrophoresis in space for the separation of isoenzymes. During the early phase of Space Station, pilot plant studies will demonstrate the capability to produce isoenzymes in commercial quantities. Production facilities will then be developed for the manufacturing of isoenzymes in space. The production level will be increased with full scale production by 1994. As shown in Figure 3.1.4-3, typical six-month in-space production cycle will consist of five monthly processing periods and one month for maintenance (if required).

Requirements

The isoenzyme production equipment consists of rack mounted batch electrophoresis separations and support equipment (freezer, transfer containers). Each unit with its support equipment has a mass of 200 kg and a volume of 0.5 m^3 . Power required is 375 w/unit. Raw material supply and product return is 36 kg/unit/year. Maximum storage life of raw material and product is six months. Maximum g-levels allowable are 10^{-2} to 10^{-3} g.

Pilot plant production in 1991 would involve one separation unit. Small scale production in 1992/3 would utilize two units. Full scale production would begin with four units in 1994 and would increase to 10 units by the year 2000.

Benefit Analysis

Alternative mission implementation using a free flying platform would require automated equipment and increased storage capability. Development and servicing via the STS would be required. Mission implementation using Spacelab/STS in the sortie mode would involve multiple spacelab flights. A comparison of implementation costs for initial full scale production is given in Figure 3.1.4-4. The computations are summarized in Table 3.1.4-1.

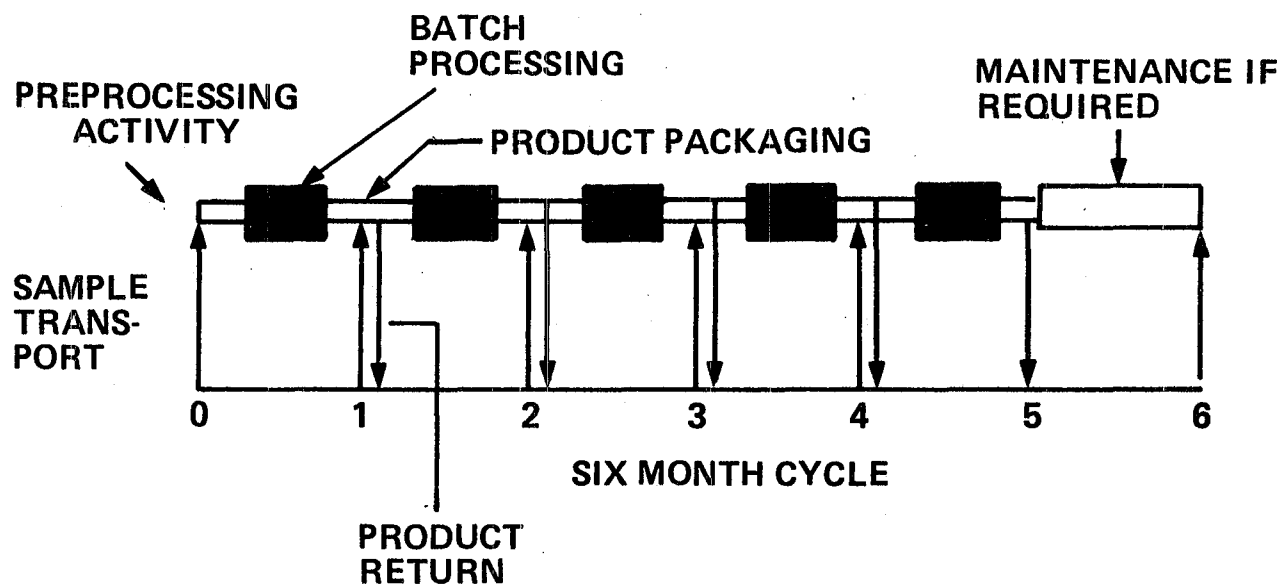


Figure 3.1.4-3. Typical Six-Month In-Space Production Cycle

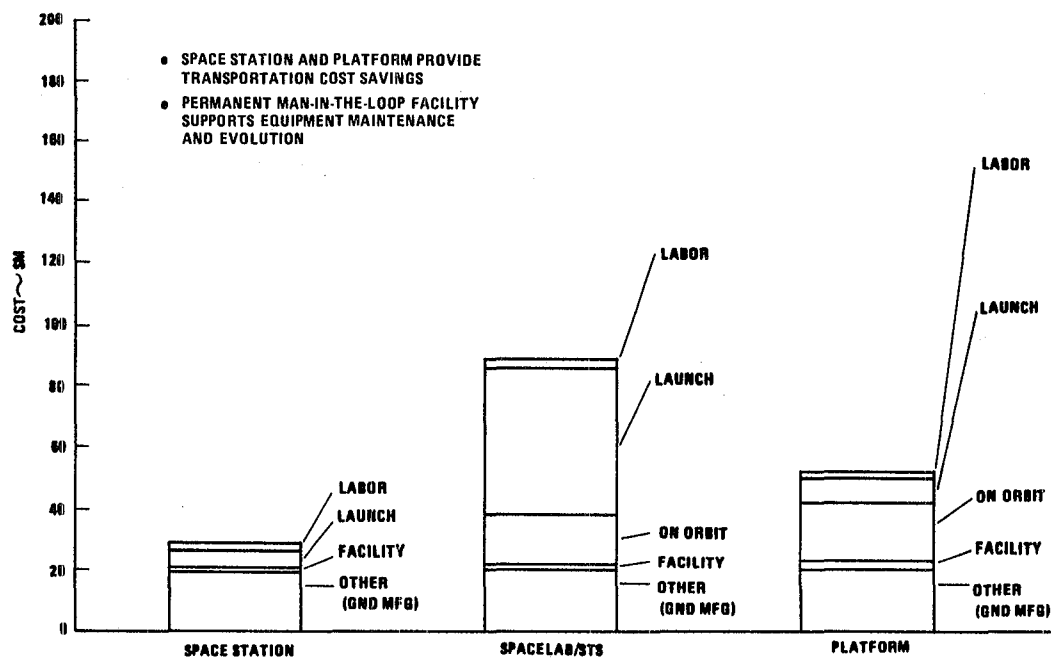


Figure 3.1.4-4. Isoenzyme Separations Mission Comparison

Table 3.1.4-1. Isoenzyme Separations Cost Comparison

COST CATEGORY		SPACE STATION		SPACELAB/STS		PLATFORM	
Labor	Space Tech. (\$10.2M/Man Yr)	2.5 Man Wks.	\$0.5M	2.5 Man Wks.	\$0.5M	1 Man Wk.	\$0.2M
	Ground Crew (\$1500/Man Wk)	*	-	*	-	*	-
Launch	Payload Launch Logistics Support (\$84.3M/Launch)	6.7% x 1 0% x 9	\$5.63M \$0M	6.7% x 10 N/A	\$56.0M -	10% x 1 0% x 3	\$8.43M \$0M
	Rendezvous Cost (\$0.88M Ea.)	6.7% x 1 + 0% x 9	\$0.07M	N/A	-	10% x 4	\$0.35M
On Orbit	Loiter Days (\$0.66M Ea.)	N/A	-	N/A	-	3 x 4	\$7.9M
	Standard EVA (\$20K Ea. Sp Sta) (\$200K Ea. STS)	N/A	-	N/A	-	12	\$2.4M
	Platform Ops** (\$100M/Year)					10%	\$10M
	Spacelab Flight (\$10M Ea.)	N/A	-	6.7% x 10	\$6.7M	N/A	-
Facility	DDT&E + Production	Apparatus	\$1.5M	Apparatus	\$1.5M	Apparatus (Automated)	\$13M
	OPS Support (15% DDT&EEP)		\$0.22M		\$0.22M		\$0.45M
Other	Ground Manufacturing		\$20M		\$20M		\$20M
TOTAL COSTS		\$27.92		\$34.92		\$52.64M	

* INCLUDED IN GROUND MANUFACTURING

**INCLUDES POCC AND TDRSS COSTS

Space Station mission implementation costs are lower than those for Spacelab/STS platform missions. Spacelab/STS mission implementation costs are higher due to the greater launch costs associated with multiple shuttle sortie flights. Platform mission implementation costs are higher due to the greater on orbit costs associated with platform use and STS revisits.

The market values of pilot plant, small scale production,, and full scale production are summarized in Table 3.1.4-2. Mission/Ground manufacturing costs for 1994 are calculated in Table 3.1.4-1 and are scaled to production rate in the other columns. Other costs are based on BUS study data, again scaled to production rate.

References

1. Beneficial uses of Space (Phase III), GE Space Division, November 30, 1975.

3.2 COMMERCIAL EARTH OBSERVATIONS

The mission that represents this category is the Stereoscopic Imaging System, an adaption of Stereosat, which has a clear user constituency and has been recommended by the Geosat Committee. This is not to imply that this is the only mission category which has commercialization potential; as a matter of fact, many of the Earth Observation missions included under Science and Application (Section 4 below) are potentially able to be "commercial".

There are at least three ways to define "commercial mission" relative to any particular flight instrument package on the Space Station. The first and most obvious is the scenario in which a commercial entity builds the flight package and pays the government to fly it on the station and charges for the data; the Stereosat belongs in this category. While there is no current commitment to a Stereosat flight schedule and while the study involved a free flyer mission and not the station, it certainly is in a class by itself in terms of a commercial venture.

The second scenario is that in which a government agency other than NOAA or NASA builds the state of the art flight package and then pays to have it flown on the station. In the current literature one can find a candidate for this

Table 3.1.4-2. Isoenzyme Production Annual Market Value

	<u>PILOT PLANT</u>	<u>SMALL SCALE PRODUCTION</u>	<u>FULL SCALE PRODUCTION 1994</u>	<u>2000</u>
SALES	\$ 20.6 M	\$ 41.25 M	\$ 82.5 M	\$ 206 M
MISSION* AND GROUND MANUFACTURING COSTS	\$ 7.0 M	\$ 14.0 M	\$ 27.9 M	\$ 70.0 M
OTHER COSTS (SALES, ADMINISTRATION, ETC.)	\$ 6.5 M	\$ 12.5 M	\$ 25.0 M	\$ 62.5 M
POTENTIAL PROFIT	\$ 7.1 M	\$ 14.75 M	\$ 29.6 M	\$ 73.5 M

*** NOT INCLUDING SPACE STATION USAGE**

scenario, namely, MAPSAT, which at this point can only be ranked as a preliminary plan.

The third scenario is a variation on the first or second in which a commercial or a government agency contracts the R&D phase and the flight equipment for the mission. This scenario has the distinct disadvantage that the broad-based user community does not participate in the R&D and thus it cannot fully benefit by the technology advancements. However, there are instances where the need for proprietary right protection may dictate such a scenario.

3.2.1 STEREOSCOPIC IMAGING SYSTEM

Introduction

In the spring of 1976, The Ad Hoc Committee on Remote Sensing from Space (the predecessor to The Geostat Committee, Inc.) held a workshop to answer the question "What do the geology-related industries want specifically from satellite remote sensing?". The 45 geologists who attended the workshop and contributed to the report entitled, "Geological Remote Sensing from Space" recommended, as a first of ten priorities, the establishment of

"Worldwide stereoscopic coverage missions (Stereosat) with a base to height ratio of 0.4 to 1.0 to maximize the vertical exaggeration for geological and structural interpretation and mapping."

As a result of this recommendation, and significant baseline design work by NASA's Jet Propulsion Laboratory (JPL), this recommendation was translated into systems specifications for a stereo satellite imaging system (designated Stereosat) and funds for designing, constructing and operating the Stereosat system were requested from NASA.

To date, Stereosat has not been approved as a new start by NASA. This is in part due to the continuing debate on commercialization of earth observations and in part due to reservations as to the cost effectiveness of dedicating a satellite to the stereo imaging mission. Implementation as a "strap on" payload on Space Station offers an attractive approach to commercially viable operations.

Market Analysis

Stereoscopic data of the earth's surface is of value for both commercial scientific geology. In general, commercial geologists are interested in specific target areas and would use world-wide survey data only to identify areas of potential interest. It is not anticipated that they would be willing to pay more than a nominal amount for world-wide survey data in which they would not have proprietary rights. The promising area for commercialization is in high resolution on-demand coverage of specific target areas in which full proprietary rights to the data would be retained by the customer.

This type of activity is presently performed by in situ field measurements or by aerial surveys. Orbital observations have some advantage over aerial surveys in that all areas overflown can be covered with minimum logistics problems and "red tape".

The stereo imaging system envisioned for Space Station would be flown in two phases: global mapping with fixed observational parameters, and target mapping with reconfigurable observational parameters. The first phase is of limited commercial potential, but is a useful precursor to full commercial exploitation. The second phase is envisioned as a mature profit-making venture.

The Geostat Committee (Ref. 1) estimated the U.S. and global markets for three years of Stereosat images at 32,000 and 132,000 data products respectively. They estimated a sale price of \$450 per product in 1978 dollars. Using their coverage rate of 44,000 data products/year and escalating the price to \$700 per data product in 1984 dollars, the annual market potential is as follows:

Fixed observational parameters (six month mission): 22,000 data products at \$15.4M sales.

Reconfigurable observational parameters (continuing missions): 44,000 data products/year at \$30.8M annual sales.

Mission Description

The objective of the initial mission is to provide global stereo mapping (resolution - 15 m) for topographic surveys. The stereoscopic imaging system would consist of a stereo film camera (Figure 3.2.1-1) that could be mounted

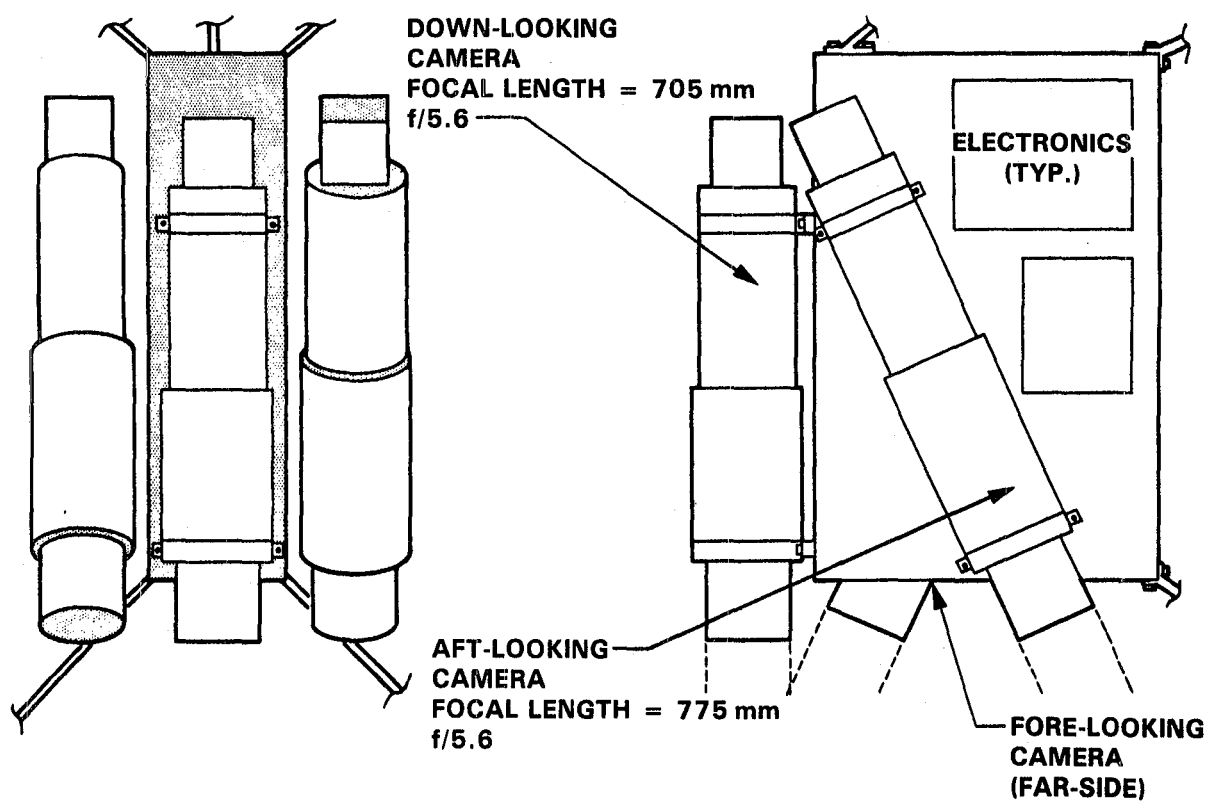


Figure 3.2.1-1. Stereoscopic Imaging System

on the space station. It would use the results/recommendations derived from earlier shuttle developmental testing. The stereoscopic imaging system would initially map with fixed observational parameters. Later developments of the stereoscopic imaging system would also have the capability to reconfigure spectral bands, bandwidths, fields of view and pointing angles per mission requirements. The initial mission duration would nominally be 6 months, with extensions for missed coverage as required. Reconfiguration of the instrument with other spectral channels and fields of view would extend its mission indefinitely.

Requirements

The instrument package is a film camera (.864 m x 1.09 m x 0.71 m) that requires continuous, unobstructed earth viewing, plus isolation from jitter (pointing accuracy - 0.1° - $.01^{\circ}$). Power requirements (50 - 75 watts continuous) and command/telemetry requirements are minimal (with the possible exception of 100 Mb/sec data rates if digital imaging is used). The stereoscopic imaging system would prefer either a sun-synchronous or polar orbit, although 60° - 65° inclination would be acceptable. The instrument package would be externally mounted (unpressurized), periodically calibrated and serviced by the non-dedicated crewman, using EVA.

Benefit Analysis

Alternative mission implementation using an unmanned free-flyer would require a sophisticated electronic sensor. Deployment via the STS, operational commanding from a ground POCC via TDRSS, and on-orbit servicing/recovery via the STS would be required. Mission implementation using Spacelab/STS would involve many Spacelab flights with no anticipated on-orbit servicing requirements. A comparison of implementation costs for the initial six month mission is given in Figure 3.2.1-2. The computations are summarized in Table 3.2.1-1.

Space Station mission implementation costs are lower than those for spacelab/STS and significantly lower than those for a satellite mission. Satellite mission implementation costs are high due to the costs of developing and operating the satellite and sensor. Space Station and Spacelab/STS offer the capability of flying a stereoscopic camera in a low cost strap-on mode.

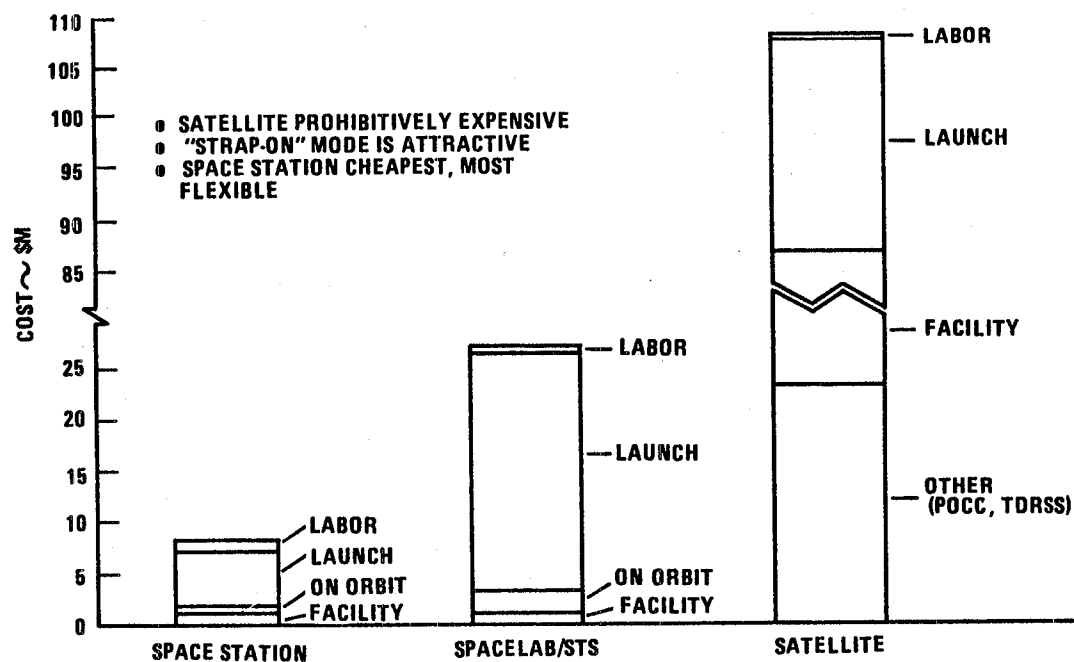


Figure 3.2.1-2. Stereoscopic Imaging System Mission Comparison (Full Earth Coverage)

Table 3.2.1-1. Stereoscopic Imaging System Cost Comparison

COST CATEGORY		SPACE STATION		SPACELAB/STS		SATELLITE	
<u>Labor</u>	Space Tech. (\$10.2M/Man Yr)	2 Man Wk.	\$0.39M	~0	-	N/A	-
	Ground Crew (\$1500/Man Wk)	3 x 24 Wks	\$0.1M	3 x 24 Wks	\$0.1M	3 x 24 Wks	\$0.1M
<u>Launch</u>	Payload Launch Logistics Support (\$84.3M/Launch)	6.7% x 1 ~0%(Film)	\$5.6M 0	6.7% x 4 N/A	\$22.4M -	25% x 1 N/A	\$21.1M -
	Rendezvous Cost (\$0.88M Ea.)	6.7% x 1 + 0% x 5	\$0.06M	N/A	-	N/A	-
<u>On Orbit</u>	Loiter Days (\$0.66M Ea.)	N/A	-	N/A	-	N/A	-
	Standard EVA (\$20K Ea.)	10	\$0.2M	N/A	-	N/A	-
	Spacelab Flight (\$10M Ea.)	N/A	-	6.7% x 4	\$2.68M	N/A	-
<u>Facility</u>	DDT&E & Production OPS Support (15% DDT&E)	Camera	\$1M \$0.15M	Camera	\$1M \$0.15M	Sensor + S/C	\$50M \$7.5M
<u>Other</u>	POCC	N/A	-	N/A	-	Eqpt & Ops	\$25M
	TDRSS					6 Mos	\$3.25M
TOTAL COSTS		\$7.5M		\$26.33M		\$106.95M	

Spacelab/STS requires numerous flights for full cloud-free earth coverage. This results in transportation costs that are much greater than those for a Space Station mission.

The market value of initial fixed parameter operation and continuing reconfigurable parameter operation is summarized in Table 3.2.1-2.

The stereoscopic imaging system would benefit: geological surveys by indicating sub-surface features, the assessment of global mineral resources, the identification of hydrological topographic features, and the delineation of faults and various soil types.

In summary, implementation of the stereoscopic imaging system via the space station is not only cost-effective, but also allows for a relatively easy on-orbit servicing capability, as compared to either the free flyer or spacelab/STS implementation approaches.

References

1. Stereo Satellite Data Product Market Assessment, Geostat Committee Stereosat Task Force, November, 1978.

Table 3.2.1-2. Stereo Imaging System Market Value

	<u>FIXED PARAMETERS</u>	<u>RECONFIGURABLE PARAMETERS</u>
SALES	\$ 15 M	\$ 30 M/YR
MISSION COSTS *	\$ 7.5 M	\$ 7.5 M/YR
OTHER COSTS (SALES ADMINISTRATION, ETC.)	\$ 3.25 M	\$ 7.5 M/YR
POTENTIAL PROFIT	\$ 4.25 M	\$ 15 M/YR

***NOT INCLUDING SPACE STATION USAGE**

SECTION 4

SCIENCE AND APPLICATIONS MISSIONS



SECTION 4

SCIENCE AND APPLICATIONS MISSIONS

4.1 SOLAR/TERRESTRIAL

The first three missions included herein; (1) Advanced Thermal Mapping Applications, (2) Soil Moisture and Snow Research and (3) Assessment and Multidiscipline Advanced Land Observation Sytem, fit both in the Solar/Terrestrial Category and Resource Observation category. Under Solar/Terrestrial they serve to study the planetary properties of the earth, including geomophology, the global distribution of snow, surface moisture and land formations; whereas under Resource Observation they are useful in the assessment and management of geologic, hydrologic and land resources. Thus, the value of these missions is augmented due to the multiplicity of the application of the data obtained. The fourth mission, Solar Terrestrial Laboratory has high scientific value within the subject category and has less direct application value in terms of earth resources, although the results of its investigations could be quite valuable in areas such as climatology.

4.1.1 ADVANCED THERMAL MAPPING APPLICATIONS

Description

The mission objective is to obtain thermal infra-red resource surveys useful in the fields of geology, geophysics, agriculture, forestry, land use, and water resources. The mission duration would nominally be for 1 year, with extensions for missed coverage as required. The experiment package, a high resolution IR Radiometer operating in the 8 - 15 micrometer range with 40 - 60 nm bandwidth (100 - 150 M resolution), would use the results derived from earlier Shuttle developmental testing involving multiband thermal imagers. The mission payload is illustrated in Figure 4.1.1-1.

Selection Rationale

Thermal infra-red mapping on a global scale would contribute valuable basic science data applicable to the research fields of land cover dynamics, vegetation resources inventory and monitoring, hydrological cycle theory, and lithologic mapping.

Accommodation Requirements

The instrument package will require unobstructed earth viewing, isolation from jitter, and pointing accuracy of 0.1° - 0.01° . Data rates will be approximately 2.5 Mbps. The advanced thermal mapping experiment would prefer an orbital inclination greater than 55° . The experiment would also be cryogenically cooled, which would necessitate periodic cryogen replenishment. The instrument's large aperture optics would require assembly in-orbit.

Space Station Implementation Approach

The instrument package would be externally assembled, mounted, calibrated, and serviced (including cryogen replenishment) by non-dedicated EVA crewman.

Nonspace Station Implementation Approach

Mission implementation using an unmanned free-flyer involves assembly, deployment and servicing via the STS and operational commanding from a ground POCC via TDRSS. Mission implementation using spacelab/STS would involve several Spacelab flights with on-orbit assembly/disassembly, and servicing.

Benefits Assessment

Space station implementation costs are lower than those for Spacelab/STS and significantly lower than those for a satellite mission. Satellite mission implementation costs are high due to the costs of developing and operating the satellite. Spacelab/STS requires several flights for adequate earth coverage, which would result in launch costs that are much greater than those for a Space Station mission.

Analysis Results

In summary, implementation of the advanced thermal mapper via the space station is not only cost effective, but also allows for a relatively easy on-orbit assembly and servicing capability, as compared to either the free-flyer or Spacelab/STS implementation approaches.

4.1.2 SOIL AND SNOW RESEARCH AND ASSESSMENT

Description

The objective of this mission is to provide synoptic and repetitive measurement of moisture content of soils and snow. Its end use will be for agriculture, water resource and climate analyses. There will be a capability

for mapping and specific observation of selected areas. This will constitute a new mission responding to the needs for more detailed knowledge of ground moisture in the decade of the 1990's.

Proper assessment of agricultural production is strongly dependent upon knowledge of the availability of moisture within the soils under cultivation and within the soils that drain into to them. The quantity of moisture present within soil also effects the availability of runoff for other purposes and reflects the subsurface water content.

Individual users have requirements that cannot wait for the completion of global mapping. Measurement of specific areas thus might be accomplished upon demand by the individual user.

Two principal sensors will be involved, as shown in Figure 4.1.2-1. Their characteristics are listed in Table 4.1.2-1:

Table 4.1.2-1. Sensor Characteristics

Name	Property Measured	Bandwidth	IFOV	Swath Width
Passive Microwave Radiometer	Surface Brightness Temperature	1.400 - 1.427 Ghz	12 Km	870 Km
Active Microwave Sensor	Surface Backscatter Coefficient	4.5 - 5.0 GHz	100 m	290 Km

The principal functions to be performed aboard the Space Station will include:

1. Receiving and inspection of components
2. System assembly
3. Mounting to Space Station with proper earth pointing orientation
4. Instrument operation from Space Station
5. Mapping operations, with a minimum man involvement (semi-automatic mode)
6. Site selection and steering of antennae to acquire data (demand mode)

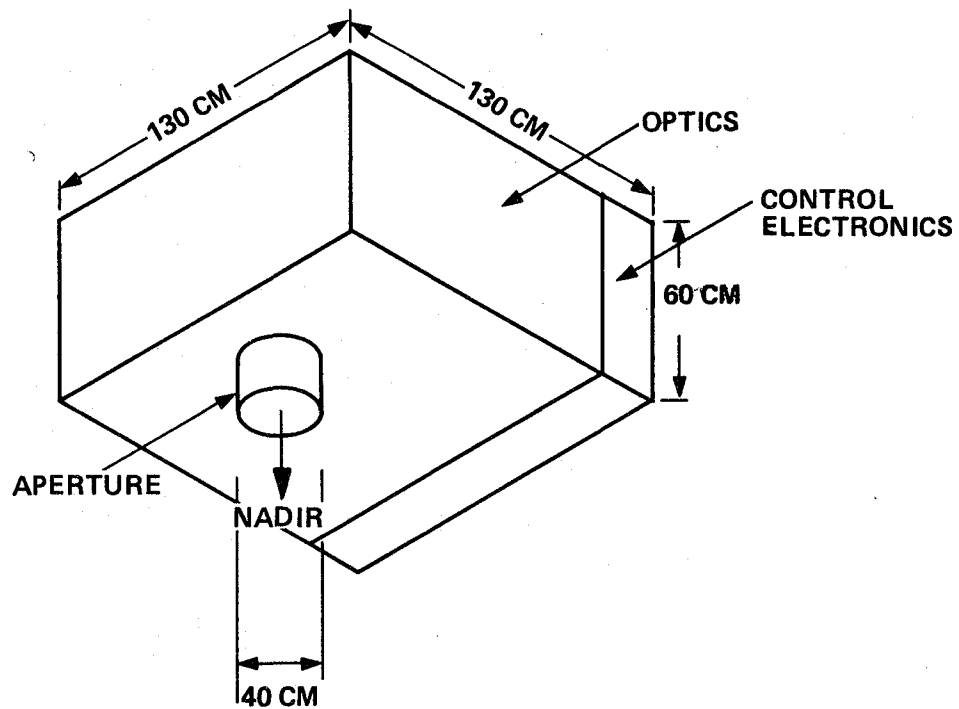


Figure 4.1.1-1. High Resolution IR Radiometer For Advanced Thermal Mapping Application

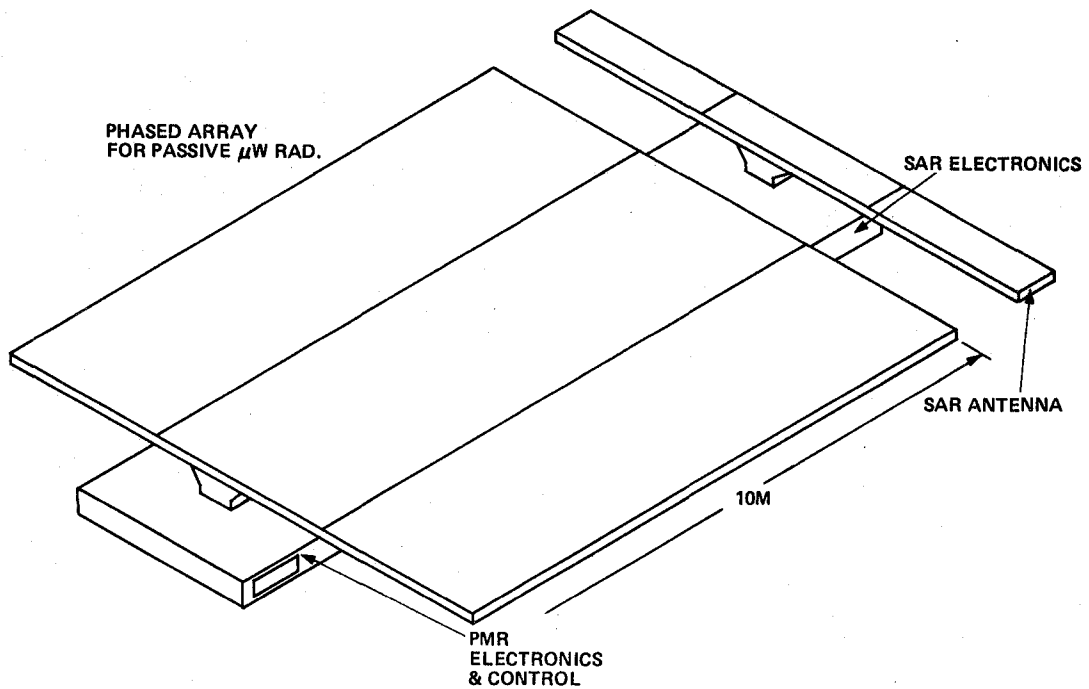


Figure 4.1.2-1. Sensors for Soil and Snow Research Assessment

7. Preventive Maintenance
8. Corrective Maintenance
9. Instrumentation Upgrade

A duration of 2-3 years is contemplated for the mission, with possible extension if necessary.

Selection Rationale

This mission will provide fundamental data regarding the availability of a critical resource. Commercial demand for data on specific sites is expected to become significant in the next decade and beyond.

The Space Station is important for this mission because of the advantages it provides in assembly and operation. Large structures such as the antennae to be used on this mission can be erected by a Space Station crew with relative ease. The flexibility of having an on-site operator also makes response to commercial requirements practical. Remote operations would require a far more expansive and sophisticated system.

Accommodation Requirements

1. Physical Structure
 - .5 x 10 m active microwave sensor
 - 10 x 10 m passive microwave radiometer
 - 550 Kg
2. Power
 - 1.2 Kw average
 - 3 Kw peak for 10 min.
 - 350 A - hr. NiCd batteries
3. Orbit
 - Altitude 465 Km
 - Inclination 60° or higher
4. Data Rate
 - 4 Mb/s
5. Pointing and Stability
 - Accuracy +0.175 Mrad
 - Stability ±10 Mrad

Space Station Implementation Approach

The Space Station provides a practical platform for assembly and maintenance of the instruments as well as housing the crew needed for these functions. Pointing and specific site observation could be controlled from within the Space Station. A more general mapping function would need only limited man involvement.

Non Space Station Implementation Approach

The basic instruments could be mounted aboard the modular spacecraft after transportation by the Shuttle. Assembly would take place from the Shuttle bay. Operation would be ground controlled, sacrificing site selection flexibility. Maintenance would require additional shuttle flights.

Benefits Assessment

Knowledge of soil moisture will contribute directly to agricultural planning, a function of great economic and social significance. Similar agreements can be made for knowledge of general water resources and climate assessment.

4.1.3 MULTIDISCIPLINE ADVANCED LAND OBSERVATION SYSTEM (COMBINES ALOS, GEOLAB, AGRILAB)

Description

The objective of this mission is to provide multimodal high resolution mapping of remote areas of the world. Vegetation cover will be identified, its volume estimated, and crop yield and vigor assessed. Geomorphology and land cover will also be stereoscopically mapped. A capability of providing multispectral data with 10 m resolution in the visible and IR and 30 m in the shortwave bands will be available.

This mission stems from the success of Landsat 1, 2 and 3 and responds to the needs of the user community of depletable geological resources currently being addressed by the French SPOT program and German and Japanese plans to fly SAR and MLC type instruments. Furthermore, it results from needs expressed in a U. S. Department of Agriculture (USDA) report (Integrated Remote Sensing System Studies, chaired by Mr. Robert Cooper) to the IRS panel in 1979. Because of redundancy in instrumentation the above goals can be combined with those for a more general advanced land observing system (ALOS).

The primary mission Sensors are a SAR, a pushbroom MLA, and a VLAMMR, as illustrated in Figure 4.1.3-1.

This mission will provide image information that can be used to determine mineralogical structure, morphology, surface cover characteristics, vegetation and crop condition. Other parameters that will be addressed are water, temperature and humidity. A significant number of users purchase analyses based on evaluation of the characteristics of such remote imagery (e.g., General Electric GEOPAK), usually in the form of statistical evaluations of the probability of occurrence of certain deposits or crop yield. Some users buy the digitally enhanced imagery or special photo products made by combining imagery derived from more than one instrument such as the SAR/SAT imagery offered by Aero-Service.

The principal functions to be performed on the Space Station will include:

1. Receiving and inspection of components.
2. System assembly.
3. Decoupling (if necessary).
4. Instrument operation from Space Station.
5. Typical operating mode is automatic. Supervised selection of sites of opportunity will be performed by the astronaut.
6. Supervised Image Data pre-processing.
7. Selection of data and choosing of channel for transmission to ground.
8. Periodic re-calibration.
9. Preventive maintenance.
10. Corrective maintenance.
11. Instrumentation upgrading and replacement.
12. Operations Upgrade.

Mission life is a minimum of two years, but five years or more is desired. Cyclic coverage requirements range from 3 to 6 days for crop yield assessment to 20 cycles per year for certain geological features. Some parameters may need coverage only once during the mission.

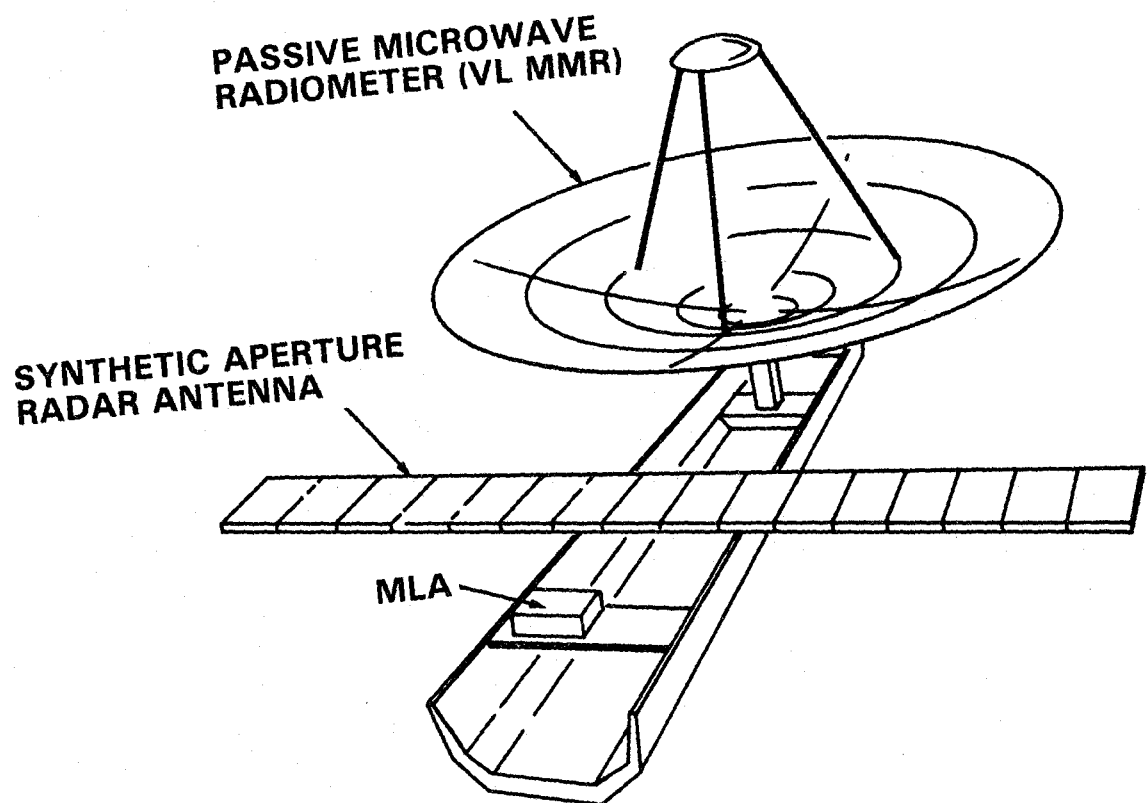


Figure 4.1.3-1. Multidiscipline Advanced Land Observation System

Selection Rationale

Knowledge of, and planning for, world-wide resource and food production and their associated economic and human implications are critical. This mission provides an analytical source of information far in excess of that planned heretofore and so it becomes a unique and powerful tool in resource planning and initialization.

Assembly of such a complex system would be very difficult using anything smaller than the Space Station. Similarly, operation and data management would tax a ground based approach and maintenance using the Shuttle alone would be impractical.

Accommodation Requirements

1. Sensors and mission modules.

- 10 m resolution multiband SAR.

Antenna	1 x 4 x 30m	216 Kg	200 W (RF)
Transmitter	.3 x .4 x .8 m	60 Kg	600 W
Receiver	.2 x .3 x .3 m	10 Kg	30 W
Power Module	.3 x .3 x .7 m	40 Kg	220 W

- 5 m resolution push broom multi-spectral linear array and associated electronics; 1 x 2.5 x 2 m, 250 Kg, 250 W, data rate 400 Mbs.
- 10 Km resolution VLAMMR (Very Large Antenna Multichannel Microwave Radiometer) Antenna; 5m x 25mD, 300 Kg, Receiver; .5 x .5 x .5 m, 15 Kg, 30 W.

It is also expected that a nadir-oriented imager with three separate receptors will provide orthographic multi-spectral imagery and mono-spectral stereographic imagery. An optical fluorescence sensor would also be used.

Other instruments such as the Large Format Camera (LFC) could be used, adding significantly to the data received, but at a significant increase in weight (511 Kg), size (3 m), and power (700 W).

The total facility weight and power requirements are expected to be below 1300 Kg and 6 Kw.

2. Orbit

A sun synchronous orbit of about 900 Km altitude is contemplated. One specific proposal is given below:

Altitude	882 Km
Period	102.72 minutes
Coverage Cycle	52 days
Descending Mode Time	9:30 AM
Inclination	98.95°

This orbit will provide next-day coverage of the adjacent ground track, thus providing consistent data and coverage of the earth below 81° latitude seven times a year.

3. Data

Data rate will exceed 300 Mbps.

4. Pointing

A pointing accuracy of 6 arc seconds and stability of 0.4 arc seconds will be needed for the stable platform supporting the MLA.

Space Station Implementation

The Space Station provides an optimum support for the establishment in orbit of such a large facility, which could be a free flyer or an externally mounted payload (which would necessitate a lower orbit, compatible with the crew).

The mission components can be transported by STS. The specially trained crew needed for this assembly will then use the Space Station as a staging area for assembly of the mechanical structure and modular elements of the sensor and instrumentation system. It will also provide a shirt-sleeve environment for pre-assembly testing, calibration and repair of critical elements. After module testing the facility will be completed external to the Space Station and a full system checkout and calibration completed in its actual operating environment. After decoupling the modular spacecraft and its facility from the Space Station, the operation will be conducted remotely from that platform.

Due to the large volume of data that may have to be handled, estimated to be over 400 mbits per second, it might be necessary to provide capability for on-board data analysis and evaluation. This would allow data and data channel selection for downlinking. Another mode of operation would involve episodic coverage of unexpected events. A trained image data analyst would review three selectable bands on a color CRT display, and select sites of opportunity and electronically tag them for subsequent coverage.

Non Space Station Implementation Approach

The mission components could be delivered to orbit by the Shuttle, assembled/erected by the Shuttle crew and operated from the ground. Space limitations inside the Shuttle would restrict shirt-sleeve operations. The on-board checkout of the system would require direct link to the ground, since the Shuttle data system DMS would not be able to handle the data load. Servicing would require additional Shuttle flights.

Benefits Assessment

Implementation of this mission would provide information of next importance to world food production and discovery of depletable mineral resources; thus, the economic and social benefits are very large.

Space Station assembly appears to be the only practical alternative for such a large complex system. Data management and spacecraft maintenance would also be greatly aided by proximity of skilled personnel.

4.1.4 SOLAR TERRESTRIAL OBSERVATORY

Description

The objective of this mission is to conduct long-term coordinated studies of the coupling between the sun, solar wind, magnetosphere, ionosphere, and the earth's atmosphere. Such multidisciplinary studies will lead to a better understanding of the processes that couple the solar-terrestrial system, and ultimately influences our communications (ionosphere effects), weather, and climate.

This initial Solar Terrestrial Observatory (STO) contains instruments that address eight key scientific objectives: 1) solar variability, 2) wave-particle processes, 3) magnetosphere-ionosphere interaction, 4) global electrical efforts, 5) upper atmospheric dynamics, 6) middle atmospheric chemistry and energetics, 7) lower atmospheric turbidity, and 8) planetary atmospheric waves. The initial STO will address these objectives through coordinated measurements with 16 instruments. In addition, the use of a maneuverable recoverable subsatellite and multiple ejectable probe subsatellites will permit the remote local measurement of particles, magnetic fields, and plasma waves. The specific instruments for an initial STO are

listed in Table 4.1.4-1 together with the associated weights, powers and data rates. A representative mission configuration is given in Figure 4.1.4-1.

This mission requires many instruments, some quite large; these components (instruments or instrument groupings) must then be mechanically, electrically, and sometimes thermally integrated with the Space Station and then mutually aligned. Since at least one of the wave injection (WISP) antennas must be very long, this experiment will also have to be assembled or deployed using by crew assistance. The chemical release module and ejected subsatellites will occasionally have to be replaced. At intervals, the maneuverable/returnable subsatellite will have to be recharged with propellant.

While the ST0 is given a nominal life of five years, no specific lifetime can be properly assigned to a Space Station ST0. Initially, the ST0 will be brought into full use, after on-orbit checkout. After a period as short as a year, some instruments or instrument models may be replaced with improved versions or even replaced with other experiments. Thus, the Space Station-based ST0 is likely to be a continuously evolving/renewable association of instruments, with no formal ST0 lifetime.

Selection Rationale

The primary potential benefit from this mission consists of a greatly improved understanding of the physics and other processes that couple the sun to the earth, with the resulting additional benefits of better earth communication and climatic predictions. One example of apparent relationships that are not well understood is the correlation between the 22 year solar magnetic cycle and recurrent drought in western North America. A statistical relationship has also been found between short term changes in atmospheric circulation patterns and solar wind conditions. Since observed atmospheric effects tend to be much more energetic than the energy of any correlated solar effect, how the atmosphere picks up and amplifies the solar variations needs to be determined. This ST0 will address these and many other solar-terrestrial interactions.

Accommodation Requirements

The initial ST0 mission consists of 16 instruments plus several subsatellites, as summarized in Table 4.1.4-1. Table 4.1.4-1 also lists estimated mass, power and data rate for each instrument. To further explain, the chemical

Table 4.1.4-1. Initial Instruments for Solar Terrestrial Observatory

<u>Instrument Type</u>	<u>Instr. Mass (kg)</u>	<u>Instr. Power (Watts)</u>	<u>Data Rate (kbps)</u>
<u>Solar Measurement Instruments</u>			
Total irradiance monitor (ACRIM)	20	10-13	.2-.5
UV irradiance monitor (SUSIM)	95	100	2
Soft X-ray Imaging Telescope	50	50	100E
White Light Coronagraph*	85	50	130
Resonance Line Coronagraph*	200	100	400
Subtotals	<u>450</u>	<u>310</u>	<u>632</u>
<u>Magnetospheric/Ionospheric Instruments</u>			
Chemical Release Module	TBD	TBD	-
Particle (electron/ion) injector (SEPAC)	650	1000-3000	-
Wave injector (WISP)**	750	1000-7000	-
Low light level TV (AEPI)	175	500	100E
X-ray telescope (AXET)	210	250	100E
Multiple ejectable probes (subsattelites)	1700	450	TBD
Single maneuverable/recoverable subsat.	450	50	TBD
Subtotals	<u>3935</u>	<u>3250-11250</u>	<u>200</u>
<u>Atmospheric Measurement Instruments</u>			
Lidar for clouds and haze (nadir)	1300	2000	100R
Earth radiation balance monitor	61	50	1
IR absorption interferometer (CIMATS)	100	160	3
UV and visible imaging spectrometer	60	40	100E
Upper Atm. Temp. Sounder (ISAMS)	85	150	0.8
Upper Atm. Wind Sensor (HRDI)	84	82	4.5
Subtotals	<u>1690</u>	<u>2482</u>	<u>209</u>
Grand Totals	6075	6042-14042	1040

NOTES: * Instrument must be rolled about sun-line

** One of the antennas is at least 50 meters long

E = Estimated

R = After on-board data selection and compression

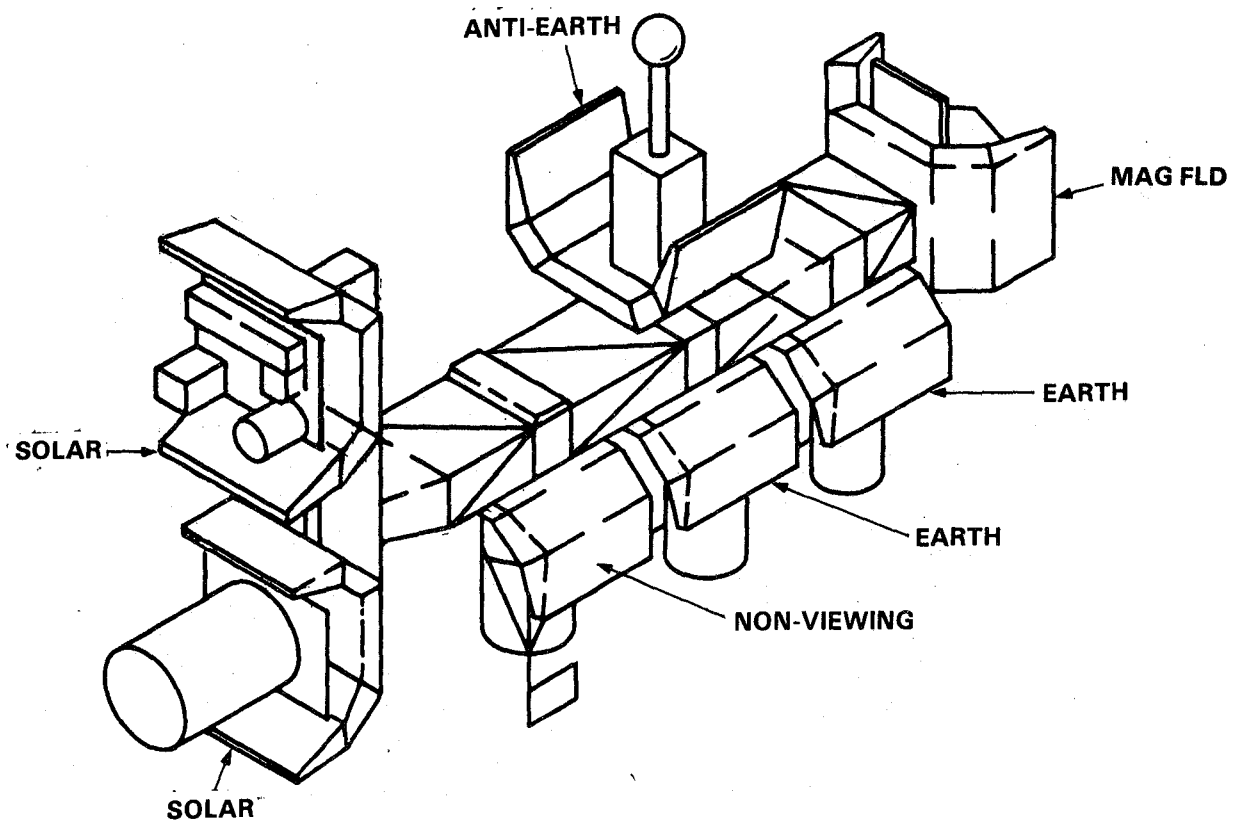


Figure 4.1.4-1. Solar Terrestrial Observatory

release module, particle injector (SEPAC), and wave injector (WISP) are all intended to temporarily modify the local and nearby ionosphere/plasmasphere, during a period in which the X-ray telescope (AXET) remotely observes the resulting back-scattered X-radiation and low light level TV observes auroral patterns. Finally, the various subsatellites are intended to measure electron and ion densities and energies, magnetic fields, and plasma waves at locations remote from the ST0, both during modification (SEPAC, WISP, etc.) and in the absence of modification of the ionosphere/plasmasphere.

As also shown by Table 4.1.4-1, the maximum electrical power which could be demanded by simultaneous operation of all the ST0 experiments is large (14 kW). However the duty cycle will vary from instrument to instrument. Some instruments will be on continuously, such as the solar irradiance monitors and perhaps most of the other solar-looking instruments. However many of the magneto-ionospheric instruments (especially the chemical release module and the particle and wave injectors) will be used at a rather low average duty cycle.

Generally there will be heavy use of instruments only during periods of magneto-ionospheric modification and during periods of unusual solar activity. It is estimated that routine monitoring will use about 1000 watts, with all or most systems operating at about 6000 watts for only a few (e.g. 4) hours a day. Use of the particle and wave injectors at their peak output levels will be relatively infrequent.

It is desired that the ST0 be located in an orbit of about 300-400 km altitude, with an inclination of at least 57° .

The Table also shows that the maximum data rate can exceed 1000 kbps (to perhaps even 12000 kbps), but such high total data rates can occur only during the 4 hour heavy operation period. During the more common 20 hour monitoring (or "standby") period, the data rate should be less than 500 kbps. Note that the lidar raw data rate is reduced from about 1000 kbps to about 100 kbps using special on-board computerized data selection and compression techniques. In all cases, all data will be routed to and stored in the Space Station until transmission to ground bases. It is assumed that at least one such dump is possible per orbit.

Considerable crew EVA time may be needed for ST0 assembly and deployment onto the Space Station, for instance, the wave injector's long antenna may need EVA work. Subsequently, the lidar's laser module will need regular servicing (flashlamps and dyes, if used) which could be done inside the Space Station with EVA's to remove and replace the laser module to service. Also, the chemical release module and ejected subsatellites will have to be occasionally replaced, and the maneuverable/returnable subsatellite will have to be refueled with propellant. It should be noted that the ST0 mission is sensitive to releases of gas, water, and EMI, all of which disturb the local magnetosphere/ionosphere being measured.

The Space Station crew will control or initiate and monitor the ST0 periods of high activity and those instruments and subsatellites which are related to those periods.

Some ST0 instruments must point at the sun, some at the earth (nadir, limb or controllable intermediate points), and some in still other directions. Those instruments which require relatively high accuracy pointing (less than 0.1°) will need their own pointing control system. Some imaging experiments, such as AEPI, may be monitored by the crew and controlled on images of special interest.

Space Station Implementation Approach

The Space Station will provide the opportunity to pursue a long-lasting, constantly evolving ST0 mission with in-space refurbishment of modules which require service (such as lasers), and replacement of modules (chemical release type) and subsatellites. With the Space Station, such maintenance, repair and replacement activities can be performed as soon as needed, with minimum down-time.

The ST0 mission instruments may be grouped on Shuttle pallets according to target (sun, earth, etc); these pallets will be attached to that external part of the Space Station which gives best access to the desired target. Of course, electric power, data, control and in some cases perhaps thermal transfer connections will have to be made to the Space Station. No use of OTV is anticipated, however, the maneuverable/returnable subsatellite must be remotely controlled, either automatically or remotely by a Space Station operator.

The Space Station crew would not only assemble, deploy and check out the mission instruments, but would also perform a monitoring/initiating/control function during periods of high ST0 mission activity.

Given the multiplicity of instruments, targets, and technologies involved in the ST0 mission, the mission will be most fruitful if all the ST0 operation are coordinated from both an operation and data management points of view. Thus the various ST0 observations must be organized through a control center. If this ST0 control center is located in the manned Space Station, a suitably trained member of the Space Station crew can always be available to make the necessary decisions to tailor observations and experiments to specific solar, magnetospheric, and atmospheric conditions arising during the mission. The data must ultimately be transmitted to ground stations for analysis, but the use of on-board control will result in less transmission of more useful data. The technical crew member would also monitor the imaging systems and make any adjustments in their field-of-view. Due to the high data rate, lidar system should have the capability for automatic data selection and compression by an on-board (or on-lidar) microcomputer.

Such a Space Station based ST0 is scheduled to start in the mid 1990's, and last indefinitely due to the maintenance, refurbishment and mission modification capabilities of the Space Station system.

Most of the ST0 instrument types have already been flown on satellites, although some are still under development for space-qualified use. The latter category includes the lidar's laser, the particle and wave injection systems, the chemical release module, and the recoverable subsatellite.

Once the ST0 is in operation, logistics support includes replacement of laser modules or laser flashlamps and dyes, ejectable subsatellites and the replacement of propellant for the maneuverable and subsatellite. Due to the resulting gas emission from cryogenics, cryogenic coolants are not as desirable as cold detectors cooled by a suitable combination of radiation, thermoelectric, and/or Sterling cycle coolers.

Non-Space Station Implementation Approach

This approach will be implemented through the use of several Shuttle flights, with the Shuttle crew assembling the ST0. If this in-flight assembly is not

feasible during the short flight times available, then the ST0 would be much more limited in scope in order to permit it to fit pre-assembled into one Shuttle flight. Alternately, the ST0 could consist of several separate but coordinated satellites, each of which must also supply its own power, data storage, and ground/TDRSS communication capabilities. Greater use must be made of automated response to solar/magnetosphere conditions, with any human intervention or control being ground-based. When problems develop or consumables need replacement, the ST0 instrument down-time will be much greater than if the ST0 were part of a manned Space Station.

Benefits Assessment

The Solar Terrestrial Observatory (ST0) will greatly increase our understanding of not only plasma wave-particle interactions, but also how the sun influences the earth and its ionosphere. For example, statistical evidence indicates that both solar radiation and particle interactions heat the upper atmosphere and affect its winds while also influencing middle atmospheric chemistry (such as the ozone balance). Finally, there is long term statistical evidence that relatively small solar variations can produce relatively large lower atmospheric climate changes. Thus by improving our understanding of solar-terrestrial interactions, the ST0 mission will improve our ability to predict variations in climate and communications (ionosphere effects).

The Space Station ST0 will yield a better integrated and/or more complete ST0 with less down-time and greater operational flexibility than would be the case for a non-Space Station ST0. The manned Space Station will allow better ST0 response to unanticipated solar and/or magnetospheric conditions which are particularly suitable for conducting magnetospheric experiments and also for observing special magnetosphere/ionosphere/earth atmosphere effects. The manned presence in a Space Station ST0 will also result in better mission reliability in terms of much shorter down-time as the result of a failure or depletion of consumables. The Space Station can carry consumable replacements as well as spare components or sub-modules for those considered most likely to fail. The constant presence of a crew with EVA capability will then permit the relatively rapid return of the ST0 to operational status.

Of course, any ST0 mission which is Space Station mounted will have most of its basic services supplied by the Space Station (electric power, data storage, computer capabilities, and communications to ground via TDRSS), and as such, will result in a significant mission cost savings as compared to any self-supporting free-flying non-Space Station mission design. All of the above considerations mean higher ST0 mission effectiveness at lower cost if the mission is part of a manned Space Station.

4.2 GLOBAL ENVIRONMENT

The missions included herein under the Global Environment discipline address a large spectrum of environmental issues, including:

1. The delineation of ocean currents.
2. Support of meteorological and climatological models through precise measurements/wind velocity, sea state, distribution of water vapor and precipitation and vertical temperature profiles including surface temperature.
3. Effects of pollutants on atmospheric radiative transfer.
4. Concentration distributions of ozone, chlorofluoromethanes and other trace species.
5. Meteorological effects upon atmospheric composition and radiative transfer.

While scientific in nature, these investigations will be highly relevant to the solution of environmental problems such as atmospheric pollution, the attainment of accurate long-range weather forecasting, and the prediction of long-term climatic trends and cycles which so vitally affect human endeavors.

The use of the station in conjunction with these missions will be very beneficial, since the instrument complements and observational operations are large and complex and will require periodic maintenance, repair and reconfiguration. The synergistic effect of concurrent measurements on air quality, as well as ocean and air circulation dynamics, cannot be underestimated in terms of ease of data interpretation and possibly shortening the research cycle.

Due to the global nature of the experiments, the missions require high orbital inclinations, preferably polar. The altitude choice for the missions must consider factors such as revisit cycle, swath-width of F.O.V. limited radiometers/spectrometers, and the "diurnal" cycles controlling the time of day or sun angle of the observations.

4.2.1 ATMOSPHERIC RESEARCH PAYLOAD

Description

The objective of the mission is to study the atmosphere and the processes occurring therein. The global atmosphere, its properties and composition is to be studied emphasizing the troposphere and the stratosphere, but extending through the mesosphere into the thermosphere. The processes include the radiative, chemical (including the various elemental cycles and both gaseous and aerosol states) and dynamics as well as the coupling among these, on various scales starting from the microscale.

This mission is a combination of Lower Atmospheric Research Satellite (LARS) and Upper Atmospheric Research Satellite (UARS) Programs. It is expected that UARS will have flown before the Space Station, but that additional data from at least some of the instruments will still be needed. Results from the UARS mission (1988 launch) could be used to select key instruments for this mission. Orbital parameters for LARS and UARS are similar enough to permit their using the same platform with the advantage of the synergistic coupling of the data.

The major needs for scientists in predicting and interpreting atmospheric effects, is for data on atmospheric composition and its variations, and for information which will permit an understanding of such data and their effects. The data on atmospheric composition, especially for trace species which have been proposed for UARS and LARS will provide data on many trace species as well as certain meteorological and spectral data needed in conjunction with such data. The measurements are designed to answer the scientific questions which will permit an understanding of atmospheric pollution and other problems.

The major instruments will be fully-developed or advanced versions of the sensors identified in Table 4.2.1-1.

Table 4.2.1-1. Atmospheric Research Payload Sensors

		<u>Principal Measurements</u>
HALOE	Solar occultation gas filter radiometer	TS, P
MAPS	Gas filter radiometers	TS
PMR	Pressure Modulated Radiometer	TS
ISAMS	Gas filter radiometer	TS,T,Wind
Crygenrc	IR Radiometer/Spectrometer	TS
ATMOS	Interfermoeter spectrometer	TS
CIMATS	Partial scan interferometer	TS,T
WINTERS	Michelson interferometer	Wind,T
HRDI	Fabry-Perot interferometer	Wind,T
CLAES	Etalon spectrometer	TS,T
Temperature Sounder		T
UV	Visible spectrometer	TS
SBUV	Scanning UV double monochromator	Ozone
SUSIM	Double dispersion scanning UV Spectrometer	Solar irradiance
SOLSTICE	UV Scanning grating spectrometer	Solar UV
Submillimeter wave radiometer		TS
Passive microwave radiometer		Water Vapor,T,Precip
ACRIM	Active cavity for UV radiometer	Solar irradiance
Microwave limb sounder		TS,T,P,Wind
PEM	Particle spectrometer	Particle energy
MLA	Multi-spectral linear array	Surface T

(Code: TS = trace species, T = Temperature, P = Pressure.)

While there is some overlap in the function of the various instruments, there is no complete duplication of the functions of any one instrument by others. They operate in different atmospheric regions, different spectral regions, and measure a variety of atmospheric constituents and physical properties. The overlap which occurs will provide a check on result. Not all instruments will be carried at one time, but from time to time some instruments will be removed and others added. A typical instrument payload is shown in Figure 4.2.1-1.

Operations during this mission are:

1. Checkout and calibration
2. Activation of instruments
3. Data gathering and pre-processing
4. Activation and deactivation of solar occultation instruments each orbit
5. Control of instruments
6. Reconfiguration of payload
7. Maintenance

The mission should last at least five years. Some instruments will require continuous operation. Maintenance will be performed as needed. Checkout will be required at the start, with the installation of new instruments, and with changes in operating instruments. Calibration will be performed frequently.

Selection Rationale

This mission is selected for its high scientific value since the results will be used to understand many of the problems affected by the atmosphere; thus, the mission will ultimately have considerable socio-economic value. It is likely that instruments will be needed in routine measurements in future operational missions. The large volume, weight, and power capability of Space Station are advantageous. On-orbit replenishment of cryogenics would increase the lifetimes of several instruments. The crew would be used for on-board calibration and for changes of configuration which can be expected to be both planned and unplanned. It is not expected that all the listed instruments will be carried at once, but they will each be carried for significantly long periods (probably a year or more). There will be replacements, involving both

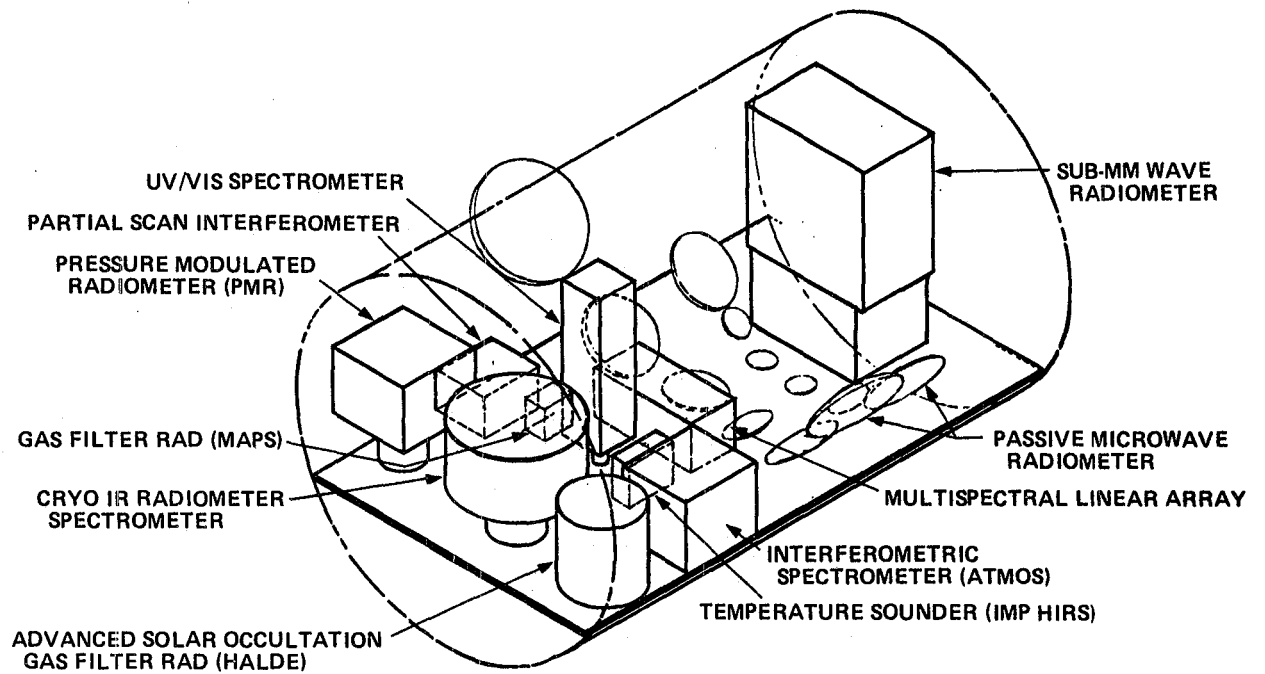


Figure 4.2.1-1. Atmosphere Research Payload (Partial)

improved versions of the same instrument and totally different instruments designed to accomplish totally different objectives.

Accommodation Requirements

The sensor characteristics are as shown in Table 4.2.1-2:

The mission is compatible with circular orbits of 500 to 700 km altitude. Although each instrument has different optimum orbital requirements to obtain the needed measurements, an inclination approaching 90^0 is desirable for the instruments.

The various instruments have different duty cycles. Some may be operated nearly continuously while others (e.g. SUSIM, ACRIM) operate only when the sun is visible and others (e.g. HALOE) operate only when the sun is in line with the earth's limb.

Space Station Implementation Approach

The recommended mode of implementation is "attached". An unpressurized pallet or platform will have all of the instruments mounted thereon. Control electronics will be placed in the pressurized compartment so that the crew may monitor and, as needed, control the data acquisition and pre-processing parameters and instrument viewing angle.

There will be ongoing technological developments and scientific advances which may make it advisable to change some instruments during the mission. The crew will replenish cryogenics as needed.

Non-Space Station Implementation Approach

If this mission were implemented as a free-flyer without Space Station, the following would be necessary.

1. Launch from Shuttle as free-flyer requiring a dedicated Shuttle launch.
2. Shuttle sortie flights for reconfiguration and changing of instruments as well as for maintenance and calibration.
3. Frequent replenishment of cryogenics if certain of the instruments are to continue to function.

Table 4.2.1-2. Atmospheric Research P/L Instruments

	<u>Overall Dimensions (M)</u>	<u>Weight (KG)</u>	<u>Power (W)</u>	<u>Data Rate (kbps)</u>
HALOE	1 x 1 x 1	97	65	8.5
MAPS	.25 x .4 x .4	20	43	
PMR	1 x 1 x 1.5	85	125	1.2
ISAMS	.8 x .6 x .9	85	150	0.75
IR Spectrometer/ Radiometer	1.5 x 1.5 x 1.4	500	60	
ATMOS	.9 x 1 x .9	215	90	100
CIMATS	.7 x .8 x .5	100	180	4.5
SINTERS		65	65	1.25
HRDI		84	82	4.5
CLAES	1.2 x 1.2 x 2.5	450	20	2.75
T Sounder	.5 x 1 x 1	300	150	2.8
UV/VIS Spectrometer	.5 x .5 x 2.3	130	40	3.4
SBUV		38	9	1.0
SUSIM	1 x 1 x .5	85	100	2.0
SOLSTICE	.3 x .2 x .1	8	4	0.25
SUB-MM Rad	1 x 1.6 x 1.8	235	470	2.0
Passive Wave	15 x 12 x 3	500	300	
ACRIM		20	10	0.5
MLS	2.2 x 1.3 x 1.9	295	400	4.0
PEM	.5 x .5 x .5	53	66	2.75
Linear Array	.6 x 1.3 x .6	150	165	58

Benefits Assessments

The value of this mission derives from an increased understanding of the atmospheric environment. This would include knowledge not only of atmospheric quality but also the atmospheric dynamics including circulation, weather, climate, severe storms and air-surface interface. The main result of this multidisciplinary mission may be a significant acceleration in the development of detailed atmospheric models to enable prediction and control of this important terrestrial resource.

The complexity of the instrument complement, the necessity for payload reconfiguration and the nature of the data acquisition and on-board pre-processing functions makes the implementation of this mission less expensive using the Space Station than the use of a completely automated free-flyer with periodic revisits by the Shuttle.

Analysis Results

It is recommended that this mission should be implemented as a Space Station attached payload for flight about 1990 or as soon thereafter as results from UARS become available to assist in planning the measurements for this mission.

4.2.2 OCEAN CIRCULATION MISSION

Description

The primary objective of this mission is accurate mapping of the earth's ocean surface topography using a nadir-pointing dual-frequency radar altimeter. When these results are combined with an accurate geoid, the necessary ocean currents to produce deviations from the geoid can be calculated. The earth's geoid can be obtained from a Gravsat type satellite as well as from ship gravity surveys. The altimeter (ALT) will also provide surface roughness (wave height) information. This mission should also include a two-channel microwave radiometer so as to allow correction of atmospheric water vapor effects on the altimeter signal. Similarly, the ALT's dual frequency will allow correction for ionospheric effects.

Since the ocean surface currents are largely driven by winds, it will also be useful to include a microwave scatterometer (like SCAT) to provide surface wind speed and direction. Another instrument which will enhance the mission,

is an ocean wave directional microwave spectrometer (such as OWDS) for the determination of ocean wavelength, wave height, and wave direction.

All of the instruments for this mission involve well-established technology or have predecessors as follows:

1. ALT had been planned for NOSS. A less accurate version was flown on SEASAT.
2. SCAT is similar to that proposed for NOAA H, I and J and is as had been planned for NOSS. The design is based on SEASAT's SASS.
3. OWDS has been flown on aircraft and is planned for use on the space shuttle.

A typical instrument payload configuration is given in Figure 4.2.2-1.

It is anticipated that the Space Station crew would provide initial antenna deployment/assembly and mission checkout. After checkout, the mission would probably be re-located remotely from the spacecraft, and retrieved only for repair or refurbishment.

The duration of each mission should be a nominal 5 years. Since only 3/4 of the earth's surface is ocean, the mission duty cycle could be as low as 75%.

Selection Rational

Since the ocean, with its great heat capacity and currents, strongly influences and moderates the earth's weather on both a global and local scale, an improved understanding of earth ocean currents and current fluctuations will aid our long range weather and climatic predictions. These same ocean circulations also determine the location the most productive seafood producing ("fishery") areas of the world. Ocean commerce often takes advantage of ocean currents to ship products at minimum cost. This Ocean Circulation mission will aid in optimizing these uses of the ocean and in anticipating changes.

Accommodation Requirements

Due to the extreme accuracy requirement on knowledge of orbital altitude (1-2 cm) the payload accommodation needs to minimize the effects of structural deflection, vibratory disturbance and attitude changes, on the distance between the sensor and the earth surface at the sub-satellite point. The

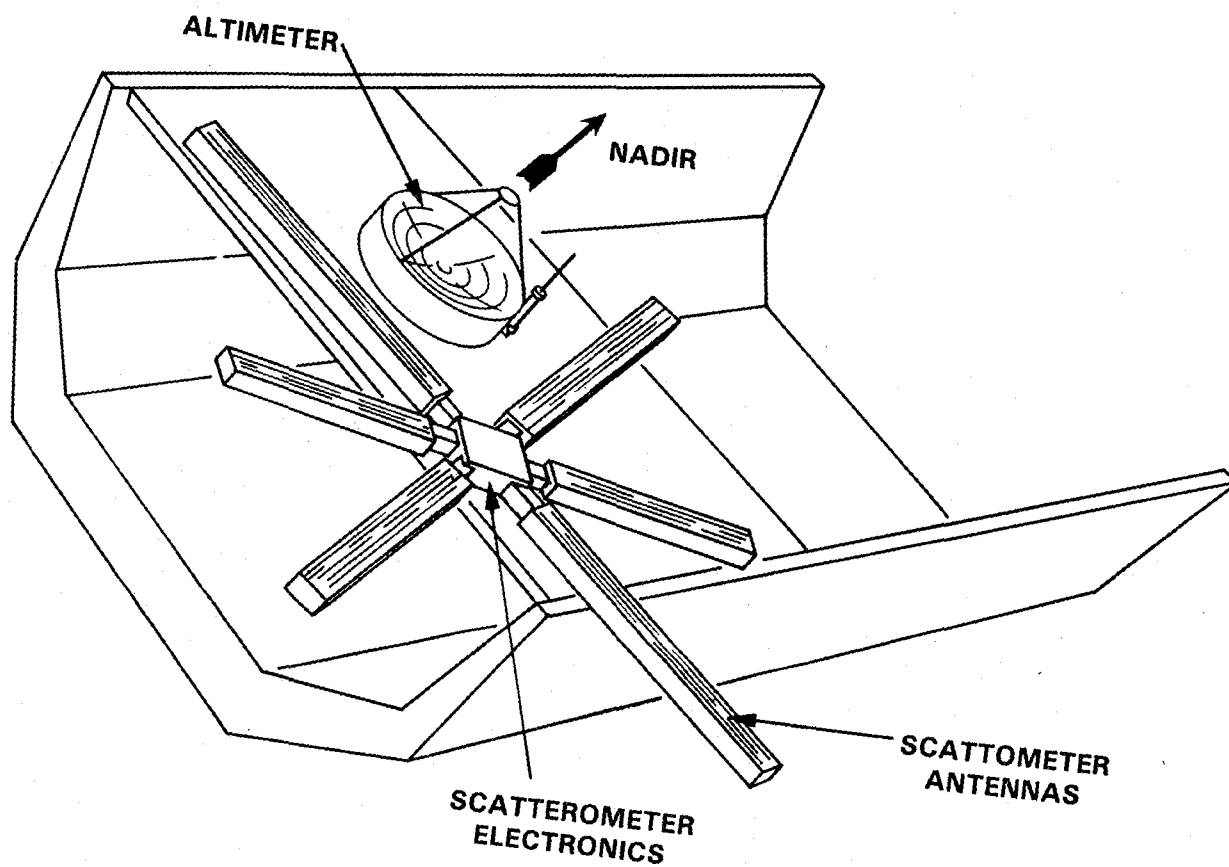


Figure 4.2.2-1. Instruments for Ocean Circulation Mission

advantage of mounting the sensor integrally to the Space Station is the decreased orbital "wobble" due to the large spacecraft inertia. The disadvantage would be the constraints associated with vibrational and translational error prevention or correction. In the free-flyer mode the mission S/C will have to supply its own power (6 to 8 square meters of solar panels), angular stabilization ($\pm 0.1^\circ$ from nadir), ALT experiment pointing knowledge (± 30 arc sec from nadir), data recording, and command and data transmitting hardware (including communication antenna). Propulsion to the mission's orbit (1300 km) and recovery for refurbishment and/or resupply of consumables (thruster gas, etc.) can be via the Space Station's OTV.

Some characteristics of the mission's sensors are given in Table 4.2.2-1:

Table 4.2.2-1. Sensor Characteristics

	Power (Watts)	Mass (kg)	Electronics Vol. (m ³)	Antenna Diam. (m)
Radar Altimeter (ALT)	200	200	0.2	2
Two-Channel Radiometer	100	200	TBD	TBD
Ocean Wave Dir. Spect.(OWDS)	200	150	0.2	1 to 1/2
Microwave Scatterometer(SCAT)	200	220	0.3	6 lin. type, ea. 3 m long

The total sensor power needs total about 700 watts. The total data rate is about 100-200 kbps.

The preferred low earth circular orbit altitude is about 1300 km, with an inclination of about 65° . A lower altitude will be acceptable if the mission is integral to the Station. This orbit will require use of TDRSS and/or the Space Station for data transfer to ground.

If a free-flyer is used, the spacecraft will be delivered to the Space Station for final deployment/assembly, such as installation of the scatterometer's linear antennas, and checkout. An orbital transfer vehicle (OTV) will then place the S/C in its final orbit. As already indicated, the OVT can return the S/C to the Space Station for refurbishment and/or re-supply of consumables such as gas for the attitude control thrusters.

Mission control can be effected from the Space Station or ground. The primary external control relates to duty cycling (about 75% "on" if used), and data dump commands.

Mission S/C nadir pointing is required, with an estimated accuracy of ± 0.1 degree. The major constraint is the extreme accuracy ($\pm 1-2$ cm) needed for orbit altitude. Including optical retro-reflectors on the S/C will aid in obtaining such accuracy via laser radar ground stations.

Space Station Implementation Approach

The mission S/C will be first taken by Shuttle to the Space Station where EVA astronauts will install the stick antennas used for the scatterometer. Similarly, it may be desirable to complete the assembly of the larger dish antennas, such as for ALT. The Space Station crew will then check out the mission instruments and S/C operation before using the OTV to place the S/C in its operational orbit.

In the event of mission S/C or instrument failure, the S/C can be returned by the OTV to the Space Station for modification, refurbishment or repair in a shirtsleeve environment. Any consumables can also be replaced, such as thruster gas. The Space Station can also be used as part of the TDRSS for data transfer to earth.

Non-Space Station Implementation Approach

In this mode, the mission S/C would be probably placed in a low earth orbit via shuttle, and then moved into its operational higher orbit using an upper stage. Thus, an upper stage must be part of the mission S/C. Furthermore, the sensor instruments would probably require a more complex and more fail-safe design to allow remote or automatic deployment of all antennas. It is possible that some of this could be done by hand via shuttle crew EVA, but with less leeway (compared to Space Station) in terms of time and complexity of crew performance. Once the S/C is in its operational orbit, it would be unavailable (by Shuttle) for repair, refurbishment and/or replacement of consumables.

Command and data transfer would be direct to/from ground or via TDRSS.

Benefits Assessment

This Ocean Circulation Mission will greatly improve our understanding of ocean currents and its fluctuations. In addition to this worthy scientific benefit, many more practical benefits will follow as discussed in more detail under "Selection Rationale". To review, this mission will also lead to a better understanding of, utilization, and prediction of changes in the earth's fisheries, as well as better weather and climate forecasting. Ocean commerce will also be aided by making possible increased efficiency of shipping.

While the Ocean Circulation Mission can be implemented by the shuttle alone, the use of Space Station will decrease the mission cost and greatly increase its lifetime. The latter is made possible through use of the Space Station plus OTV's to allow mission replacement of consumables, repair and even general refurbishment. The capability of refurbishment and modification will also provide long-term flexibility of use, and reduce the need for replacement of the original mission spacecraft.

4.2.3 IMAGING RADAR EXPERIMENT

Description

The primary objective of the mission is to use a Synthetic Aperture Radar (SAR) to (1) provide information on the status of sea ice in ocean shipping lanes, (2) assess the utility of SAR imagery in providing information relative to renewable and nonrenewable resources, (3) provide area mapping of oceanographic features using the demonstrated capabilities of SAR, and (4) investigate the utility of SAR to other areas of oceanography. A mission concept for ice processes was defined in a GE study performed under NASA Contract NAS-5-23411, Mod 47, titled "Feasibility Study, Radar for Ice Properties and Climate (IPAC) Studies". A comprehensive definition of other mission objectives can be found in a NASA/JPL document titled "Science Requirements for Free-Flying Imagery Radar (FIREX) Experiment".

A typical mission configuration is shown in Figure 4.2.3-1.

The mission should be continued daily over a period of years since (1) images of shipping lanes in sea ice have commercial impact, (2) sea ice extent together with oceanographic features should be valuable for long range weather forecasting and (3) identification, area estimation and condition assessment

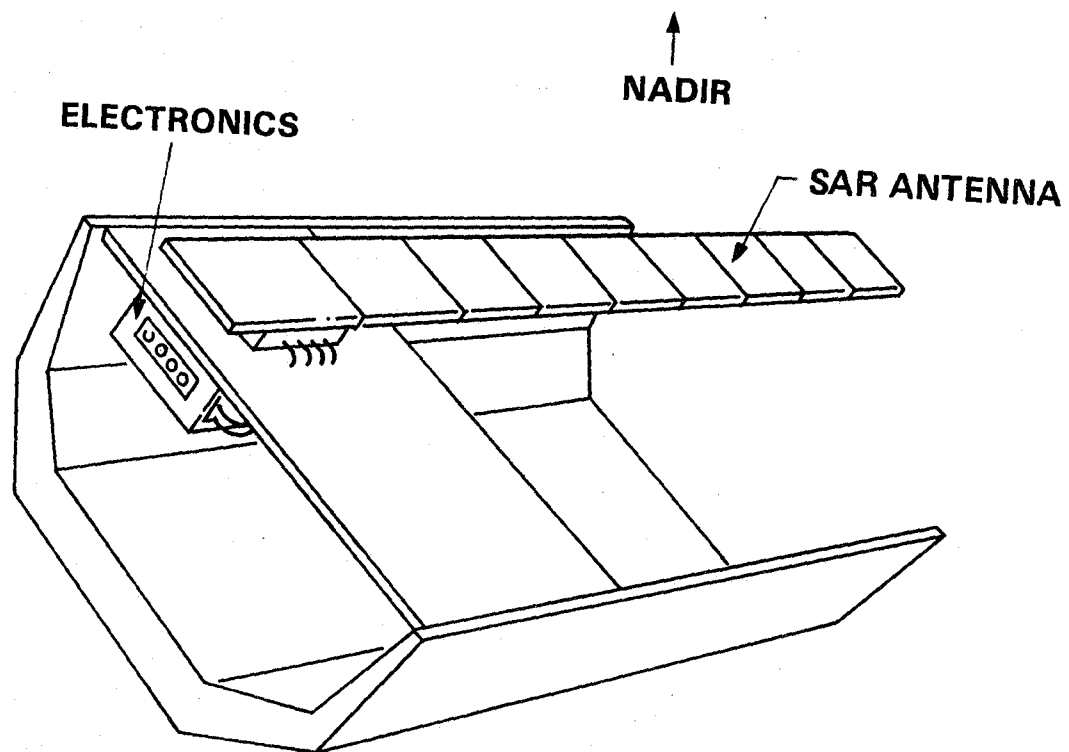


Figure 4.2.3-1. Instrument for Imaging Radar Experiment

of major agricultural crops will be valuable for annual crop production estimates.

Selection Rationale

A SAR has the potential of providing greater accuracy in predicting weather and climate and providing better definition of the navigational limits in sea-ice shipping lanes. In addition, many questions regarding the utility of SAR to measurements of renewable and nonrenewable resources and measurement of certain oceanographic properties can only be resolved be through experiments with a spaceborne SAR.

Accommodation Requirements

The size, weight and power listed on Table 4.2.3-1 are for the SEASAT SAR, but are reasonable nominal characteristics for the present system.

Table 4.2.3-1. SAR Characteristics

	Antenna	Electronics
Size	2.16 x 10.7 x 0.1 m	1.2 x 0.9 x 0.3 m
Weight	227 lbs	484 lbs
Power	0	897 W, prime

The orbit options are basically low-earth polar orbit and a high-orbit (≥ 1200 Km) coplanar polar orbit. The rationale for its selection are high latitude coverage ($\geq 60^\circ$), short revisit period (2-3 days) and wide imaging swath (≥ 200 Km).

For operation, the SAR antenna must be pointed with an accuracy of about 0.1 of the beamwidth or approximately ± 0.04 degrees.

Space Station Implementation Approach

1. SAR on Space Station

The SAR would be installed on a Space Station platform and launched by the STS where the SAR carrier would be attached to the Space Station. The SAR would then be operated over ocean ice and land areas for up to 5 years. In normal operation, the crew would make significant hardware configuration changes such as: (a) replacing antennas differing in frequency band, i.e. L-band, C-band, X-band, or

(b) re-orienting a rectangular antenna aperture from horizontal to vertical. For maintenance, the crew can be involved to replace (or repair) defective "boxes" such as the radar transmitter.

Current efforts are underway to demonstrate a short delay SAR image processing capability but with coarse spatial resolution. The amount of digital hardware required is expected to be fairly modest so that this rapid image processor capability may be integrated on the Space Station. On a real-time basis, the on-board crew could assess the images and implement changes in operational parameters or modify one hardware configuration.

2. SAR on Satellite with Space Station

In this approach the SAR would be installed on a spacecraft, launched and inserted into earth orbit on the STS. It would then be deployed and placed in its operational orbit using an OTV. If the instrument failed during its nominal 5 year lifetime, it could be retrieved by an OTV for repair at the Space Station and then returned to its orbit. In this mode of operation all data processing and evaluation would be performed on the ground.

Non-Space Station Implementation Approach

The incorporation of the SAR in a free-flying SAR on satellite without the Space Station is similar to the Space Station approach, Option 2, as discussed above. The major difference is that any repair of the instrument would have to be done by STS rendezvous with the spacecraft.

The mission operation sequences for the three implementation approaches: (1) SAR on Space Station, (2) SAR on satellite with Space Station and (3) SAR on satellite without Space Station are summarized in Table 4.2.3-2.

Benefits Assessment

Seasat demonstrated the potential value of SAR in ocean research. The Imaging Radar Experiment will be an extension of the Seasat-SIR-FIREX missions into the 1990's, using the Space Station as the base of operation. The mission addressed here is in the Science/Applications category, although there will be significant potential applications for the data in areas such as navigational aids and providing complementary data to commercial weather forecasting and mineral exploration organizations. For example, the estimated economic benefit of the RADARSAT to Canada is \$90M-150M per year by 1990 and \$110M-180M per year by 1994 through reduced shipping time, reduced operating and maintenance costs, as well as reduced costs relating to shipping hazards.

Table 4.2.3-2. Imaging Radar Experiment Mission Sequences

<u>SPACE STATION</u>	<u>SATELLITE WITH SPACE STATION</u>	<u>SATELLITE WITHOUT SPACE STATION</u>
1. SAR Installation on Space Station Carrier	1. SAR Installation on Spacecraft	1. SAR Installation on Spacecraft
2. SAR/Carrier Launch by STS	2. Launch Spacecraft on STS and Deploy	2. Launch Spacecraft on STS and Deploy
3. Carrier Attachment to Space Station	3. Operate SAR Over Ocean, Ice, Land Areas (Up to 5 Years)	3. Operate SAR Over Ocean, Ice, Land Areas (Up to 5 Years)
4. Operate SAR Over Ocean, Ice, Land Areas (Up to 5 Years)	4. Ground Data Processing and Evaluation	4. Ground Data Processing and Evaluation
5. Onboard/Ground Data Processing and Evaluation	5. OTV Retrieval of Spacecraft for Servicing (if Required)	5. STS Rendezvous with Spacecraft for Servicing (if Required)
6. Equipment Servicing/Repair/Update as Required (EVA)	6. Spacecraft Servicing on Space Station (if Required)	6. Spacecraft Servicing While Berthed to STS (if Required)
	7. OTV Return of Spacecraft to Orbit (if Required)	7. Resume Operations (Steps 3 and 4)
	8. Resume Operations (Steps 3 and 4)	

A summary of mission implementation costs is given in Figure 4.2.3-2 for the three mission options previously discussed. Space station mission implementation costs are lower in all categories except labor, where significant on-orbit technician involvement is assumed throughout the 5 year mission life.

Satellite mission implementation costs are higher due to addition of the spacecraft, POCC, and TDRSS costs and a larger initial launch share. Costs would be identical with or without a Space Station if no servicing or repair were required. The values presented assume one service/repair operation during the life of the mission. A space-based OTV is used for satellite retrieval and reorbiting if a Space Station is available, and a shuttle rendezvous and berthing is used if no Space Station is available.

A more detailed cost comparison of the three mission alternatives is given in Table 4.2.3-3. On-orbit technician support is assumed at a 10% duty cycle throughout the 5-year Space Station mission. On-orbit support for the satellite is assumed for service/repair operations only.

The initial launch share is assumed to be 25% for the Space Station mission and 50% for the satellite missions. Space Station logistic support shares are assumed to be negligible. For the satellite without Space Station mission, the service/repair shuttle launch is assumed to be shared equally with another mission, but the cost of rendezvous with the satellite is charged solely to the Imaging Radar mission. The shuttle is assumed to loiter seven days for service/repair operations.

Facility costs for the satellite missions include \$50M for a spacecraft. Instruments are assumed to cost \$25M for the satellite missions reflecting increased costs for automation and reliability compared to the Space Station mission.

For the satellite with Space Station mission, OTV flights for satellite retrieval and reorbiting are assumed to cost \$5M each.

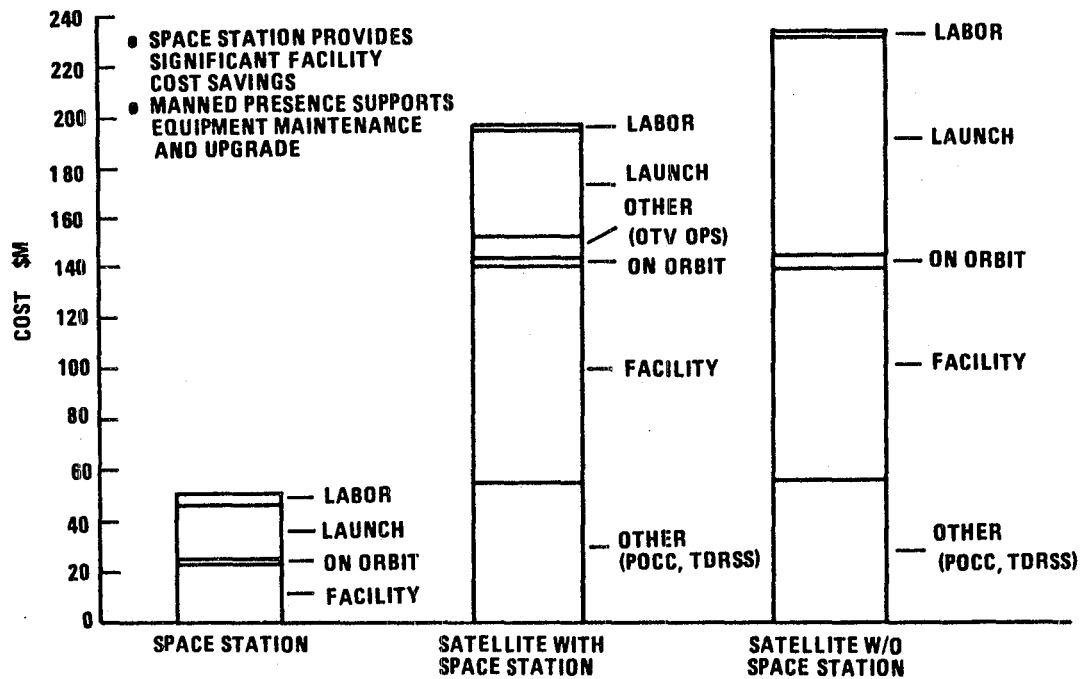


Figure 4.2.3-2. Imaging Radar Experiment Mission Comparison
(5 Year On-Orbit Life)

Table 4.2.3-3. Imaging Radar Experiment Cost Comparison

COST CATEGORY		SPACE STATION		SATELLITE WITH SPACE STATION		SATELLITE W/O SPACE STATION	
Labor	Space Tech. (\$10.2M/Man Yr)	28 Man Wks.	\$5.1M	5 Man Wks.	\$0.97M	2 Man Wks.	\$0.39M
	Ground Crew (\$1500/Man Wk)	*	-	*	-	*	-
Launch	Payload Launch Logistics Support (\$84.3M/Launch)	25% x 1 0	\$21.1M 0	50% x 1 N/A	\$42.1M -	50% x 1 50% x 1	\$42.1M \$42.1M
	Rendezvous Cost (\$0.88M Ea.)	25% x 1	\$0.22M	N/A	-	1	\$0.88M
On Orbit	Loiter Days (\$0.66M Ea.)	N/A	-	N/A	-	7	\$4.6M
	Standard EVA (\$20K Ea.)	10	\$0.2M	5	\$0.1M	7	\$0.14M
	Spacelab Flight (\$10M ea.)	N/A	-	N/A	-	N/A	-
Facility	DDT&E & Production	Instruments	\$20M	Instruments + S/C	\$75M	Instruments + S/C	\$75M
	OPS Support (15% DDT&E)		\$3M		\$11.3M		\$11.3M
Other	OTV Ops	N/A	-	Retrieval + Reorbit	\$10M	N/A	-
	POCC	N/A	-	Eqpt & Ops	\$25M	Eqpt & Ops	\$24M
	TDRSS	N/A	-	5 Yrs.	\$30M	5 Yrs.	\$30M
TOTAL COSTS		\$49.62M		\$194.37M		\$231.51M	

* INCLUDED IN OPS SUPPORT

Analysis Results

The Imaging Radar Equipment is the second step in the development of an operational radar imaging capability to be used for ocean, ice, and land feature mapping. The first step is the Free Flying Imaging Radar Equipment-A (FIREX-A) to be launched in the late 1980's. The Imaging Radar Experiment will involve a versatile SAR operating in the L, C, X and Ku-bands and will utilize real time SAR image processing. Implementation of the Imaging Radar Experiment can commence when results from the FIREX-A mission are available for use in developing optimum instrument parameters. The projected time frame for first flight of the experiment is the mid 1990's.

4.2.4 ATMOSPHERIC GENERAL CIRCULATION EXPERIMENT (AGCE)

Description

The AGCE mission objective is to experimentally model the large-scale circulation of the earth's atmosphere in hemispherical geometry. The facility will be rack mounted in a shirt-sleeve environment as shown in Figure 4.2.4-1. The working fluid, which will simulate the atmospheric motions, will be held between two concentric spheres and subjected to a radial electric field in the form of the spherical capacitor. The electric field acting on the high dielectric constant fluid will simulate the earth's gravitational force on the atmosphere. A representative pole-equator temperature gradient and the large-scale vertical stability of the atmosphere will be modeled by maintaining latitudinal temperature gradients on the spheres and by maintaining the outer sphere warmer than the inner sphere. Earth's rotation will be modeled by co-rotating the spheres.

The basic implementation concept for the AGCE is derived from a similar experiment, the Geophysical Fluid Flow Cell (GFFC), which has been built for NASA/MSFC and is scheduled for flight on Shuttle/Spacelab in the mid-eighties. The scientific objectives of the GFFC differ from those of the AGCE since it is concerned with modeling the convectively unstable circulations found in stars. Therefore, its inner sphere will always be maintained at a higher temperature than the outer sphere.

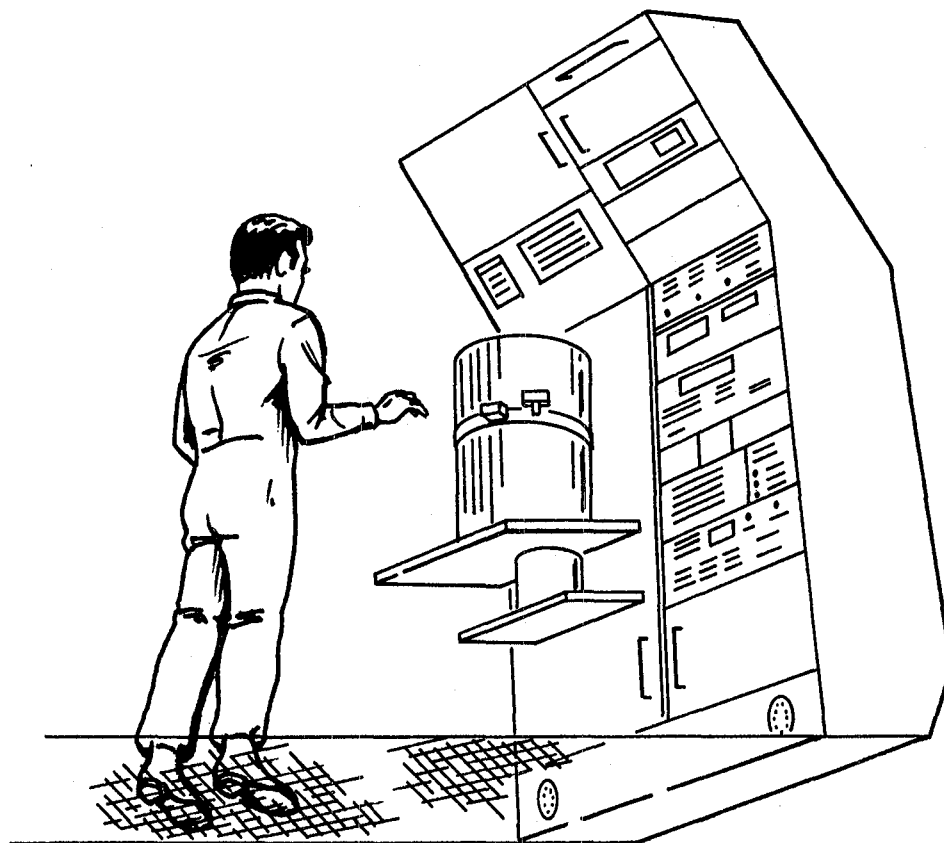


Figure 4.2.4-1. Atmospheric General Circulation Experiment Equipment

Successful implementation of the AGCE should result in improved knowledge of the atmosphere's synoptic scale weather and climate processes and lead to improved parameterization in computer general circulation models and climate models.

Optimum results from the AGCE will be achieved by a series of experiment/analysis cycles in which data is acquired using the apparatus and then analyzed either on Space Station or on the ground to determine the best parameters for use in the next data acquisition period. Ideally, the procedure should be similar to a research program conducted in a terrestrial laboratory.

Selection Rationale

There are two alternatives for implementation of the AGCE: (1) on a series of Shuttle/Spacelab flights or (2) in the Space Station. The obvious choice is to use the Space Station since the frequency and schedule of experiment cycles can be dictated by the scientist's analysis and interpretation of the experiment results rather than by the flight schedule of the Shuttle/Spacelab. This should result in a shorter duration program and a more rapid dissemination of the results to the scientific community. In addition, use of Space Station will eliminate the need for frequent and costly requalification of the experiment facility as would be required on a series of Shuttle flights.

Accommodation Requirements

The AGCE is a facility which would be placed inside the Space Station and be accessible to a scientist/technician during operation and reconfiguration procedures. The electronics and mechanical assembly required for the AGCE can be installed in a single bay rack, such as that planned for Spacelab. Total mass requirements for the apparatus is estimated at 100 Kg with an operating power requirement of 520 watts. Experiment duty cycle will consist of 1-2 days of data acquisition followed by days or weeks of analysis before the next data taking session occurs. Data from the AGCE will consist of digital science and housekeeping data generated at a maximum rate of 520 Kbps and telemetered to the PI on the ground.

Since the AGCE will be totally contained within a Space Station laboratory and does not make any remote measurements, e.g. earth observations, orbit selection is not critical. However, during experiment operation, heat rejection from the experiment apparatus to a suitable cooling loop will be required to maintain the proper thermal conditions within the fluid cell. Although some maintenance and reconfiguration tasks are planned, the experiment does not utilize any consumables.

Space Station Implementation Approach

The Space Station attributes which will enhance the performance of the AGCE include (1) the availability of a pressurized shirtsleeve environment in which the experiment can be performed, (2) the use of technicians to operate the facility and reconfigure the apparatus as required and (3) the increased versatility in experiment scheduling.

The AGCE facility will be an integral part of the Space Station for a length of time to be determined by the data obtained (e.g. 1-3 years). During this period of time, the facility would be used as needed to generate data on large-scale atmospheric circulation phenomena. This "as needed" scenario is relatively important to the AGCE since the results of any experiment trial must be analyzed to determine the optimum parameters for the next trial. The intent is to utilize the facility in approximately the same way that a ground based facility would be used, i.e. within the logistic limits of the Space Station.

Although control and operation of the AGCE facility would reside with the crew, the science data from each experiment would be telemetered to the ground station for subsequent analysis by the science team. Data available to the crew should include experiment status and health so that any abnormal operation could be detected and the experiment aborted.

Non Space Station Implementation Approach

A non-Space Station implementation approach would require utilizing the Shuttle/Spacelab facility for a series of missions. The AGCE facility could be essentially the same as in the Space Station approach, but the experiment philosophy would change. A series of experiment trials would be preplanned before flight and then executed by the Payload Specialist. In this scenario the opportunity for modifying an experiment trial based on the results of a

previous run would be difficult. In addition, the time between sets of experiments would be determined by the Shuttle/Spacelab schedule, resulting in a much longer duration experiment program than would be required by the Space Station implementation approach.

Benefits Assessment

The AGCE provides a feasible concept for modeling the general circulation of the Earth's atmosphere in spherical geometry. The experiment cannot be performed in a terrestrial laboratory because the simulation of Earth's gravitational effect on the atmosphere (i.e. the fluid confined between the spherical shells) is overwhelmed by Earth's gravity. Observation of the fluid instabilities and measurement of their characteristics under controlled conditions will enhance the understanding of baroclinic instability in spherical geometry and the associated planetary-scale circulations. This, in turn, will improve our knowledge of the atmospheric synoptic-scale weather and climate processes and lead to improved parameterization in computer general circulation models and climate models. Although the expected results from the AGCE will not provide all the answers to improved weather and climate prediction, they will contribute to an overall program for improved forecasting of large scale weather and climate trends, which has a potential economic benefit estimated to be on the order of several hundred millions of dollars annually.

As previously indicated, implementation of the AGCE on a Space Station will allow data to be obtained as desired, i.e., based on analysis of previous data, rather than when possible, as determined by the Shuttle/Spacelab flight schedule. The Space Station implementation approach should also result in a cost savings since multiple Shuttle flights, and the associated requalifications of the facility will not be required. However, the major advantage of Space Station is that it will allow the research to be conducted in a mode similar to that possible in a terrestrial laboratory.

Analysis Results

The feasibility of the AGCE has been established by a GE Study completed in 1980 in which a conceptual design of the facility was developed for implementation on Shuttle/Spacelab. That concept can also be implemented on Space Station without significant modifications. Technically the AGCE can be implemented on either the Space Station or on Shuttle/Spacelab. However, any

Shuttle/Spacelab flight of the AGCE should be a precursor to eventual long term installation on the Space Station when it becomes operational.

4.2.5 LIDAR MEASUREMENT OF AIR QUALITY

Description

The mission objectives are to measure secondary and trace gas atmospheric species, and their world-wide distribution from relatively low altitudes to as high as 100 km altitude. Other objectives include the vertical and horizontal distribution of atmospheric temperature, pressure, aerosol (haze) layers, and cloud top heights. Eventually, wind measurements should also be possible.

While no one lidar system has yet been used in space or for all the above mentioned measurements (from one system), various ground-based and aircraft-based lidar systems have already been independently used for most of the measurement categories.

The acquired information will not only aid global weather forecasting, but more importantly, will help mankind determine and understand the global effects on our environment of an increasingly crowded and industrialized world.

The lidar facility will function as a modular system consisting of three or four replaceable lasers and associated return signal detection subsystem, plus a large central telescope used to receive the return signals (Figure 4.2.5-1). This central telescope may also be used to transmit the laser outputs. Table 4.2.5-1 lists 26 different types of measurements which the lidar mission can ultimately provide, although not all 26 measurements would be obtained from any one set of mission modules. Table 4.2.5-2 gives more detailed information on possible measurements, especially of atmospheric gas species.

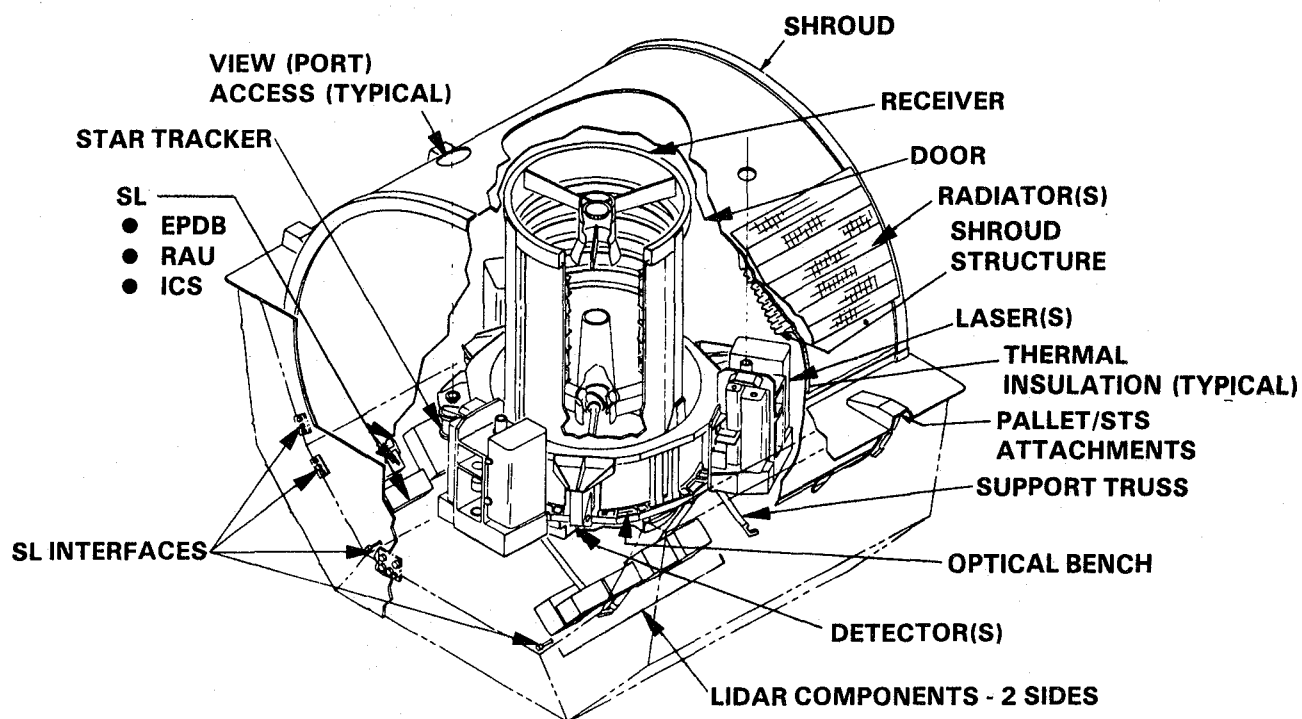


Figure 4.2.5-1. Instrument for Lidar Measurement of Air Quality

Table 4.2.5-1. Candidate Experiments

Number	Feasibility	Description	Altitude region, km	Principle	Laser	Scientific objectives ^a
1	1A	Cloud-top heights	0 to 15	Elastic backscatter	Any	3, 4
2	1A	Profiling of tropospheric clouds and aerosols	0 to 15	Elastic backscatter	Any (0.5 to 2μm)	1, 3, 4
3	1B	Cirrus ice/water discrimination	5 to 15	Polarization sensitive elastic backscatter	Any	1, 3
4	1B	Profiles of noctilucent clouds and circumpolar particulate layers	60 to 80	Elastic backscatter	Any (0.5 to 2μm)	3, 5
5	1A	Surface reflectance	Ground	Surface scatter	Any	3
6	1B	Stratospheric aerosol backscatter profiles	10 to 50	Elastic backscatter	Any (0.5 to 2μm)	1, 2, 3
7	2B	Alkali-atom density profiles	80 to 120	Resonant scatter	Tuned dye	5, 6
8	2B	Ionospheric metal ion distributions	80 to 600	Resonant scatter	Tuned dye	6, 7
9	2B	Water-vapor profiles	0 to 20	DIAL	Tuned dye	1, 3, 4, 5
10	2B	Atmospheric species measurements using CW/IR laser ground and cloud returns	0 to 30	Long path absorption (column content)	Line tunable CW CO ₂	1, 3, 4
11	2B	Chemical release diagnosis	90 to 50 000	Resonant scatter	Tuned dye	7
12	2B	Stratospheric ozone concentration profiles	20 to 60	Differential range absorption	ND=4, and/or dye	1, 2, 3, 7
13	2C	Upper atmospheric trace species measurements using two-satellite occultation	10 to 50	Long path absorption	Tunable, mainly IR	2, 3, 7
14	3B	Sodium-layer temperature and winds	80 to 110	Doppler sensitive resonant scatter	Tuned dye	5, 6, 7
15	3B	Surface pressure and cloud-top pressure and height measurements	0 to 10	O ₂ absorption (column content)	Tuned dye	4
16	3C	Vertical profiles of atmospheric pressure	0 to 10	O ₂ absorption (range resolved)	Tuned dye	4
17	3C	Temperature profile	0 to 10	Temperature sensitive O ₂ absorption	Tuned dye	1, 2, 3, 4
18	3B	Altitude distribution of atmospheric constituents using IR DIAL	0 to 15	DIAL	Line tunable pulsed CO ₂	1, 3, 4
19	3C	Cloud-top winds	0 to 15	Doppler sensitive elastic backscatter	Any narrowband	1, 2, 4
20	3C	Aerosol winds	0 to 25	Doppler sensitive elastic backscatter	Any narrowband	1, 2, 4, 5
21	3C	OH density profile between 35 and 100 km altitude	35 to 100	Resonance fluorescence	Tuned dye	2, 5
22	3C	Simultaneous measurement of metallic atom, ion, and oxide profiles	80 to 600	Resonant scatter	Tuned dye	6
23	3C	Tropospheric NO ₂ concentration profile and total burden of NO ₂	0 to 15	DIAL	Tuned dye	1
24	4	Stratospheric aerosol composition	15 to 30	Differential scattering (DISC)	Line tunable pulsed CO ₂	1, 3
25	4	NO density profiles between 70 and 150 km altitude	70 to 150	Resonance fluorescence	Tuned dye	2, 7
26	4	Abundance and vertical profiles of atomic oxygen	80 to 500	Two-photon fluorescence	Tuned dye	6, 7

^aObjective numbers denote the following:

- 1 Global flow of water vapor and pollutants
- 2 Stratospheric and mesospheric chemistry and transport
- 3 Radiative models
- 4 Meteorological data
- 5 Upper atmospheric waves
- 6 Thermospheric chemistry and transport
- 7 Magnetospheric Sun and weather relationships.

Table 4.2.5-2. Science Requirements

Parameter	Altitude range, km	Δx , km	Δz , km	Accuracy, percent
O ₃	10 to 60	500	1	10
	60 to 90		3	25
NO	25 to 100	500	3	10
NO ₂	25 to 60	500	3	10
HNO ₃	20 to 30	500	3	10
N ₂ O	10 to 40	500	3	20
OH	25 to 40	500	3	10
	60 to 90			25
H ₂ O	10 to 70	500	3	10
H ₂ O ₂	25 to 50	500	3	10
HO ₂	25 to 50	500	3	10
HCl	20 to 50	500	3	10
ClO	25 to 40	500	3	10
ClONO ₂	20 to 30	500	3	10
CH ₄	10 to 60	500	3	20
CFM's	10 to 40	500	3	20
Na	80 to 100	100	1	10
Aerosols	10 to 100	500	1	30
Wind	15 to 60	1000	3	2 m/s
	65 to 100	1000	3	10 m/s

Space Station functions for this mission are:

1. Provide operating power for non-free flying missions.
2. Checkout of the lidar modules and overall system performance.
3. Provide manual control or correction for the mission when desired.
4. Provide data storage until telemetry to ground, and probably provide some pre-processing to reduce the data storage requirements.
5. EVA functions:
 - a. Replace detector cryogenics and other consumables (maintenance).
 - b. Replace damaged parts or modules (repair).
 - c. Change experiments by changing one or more laser/detector modules (mission modification - see Tables 4.2.5-1 and -2).

The duration of each mission should be five (5) years, starting in 1995.

Selection Rationale

This lidar mission will provide detailed concentration/location information on certain atmospheric species and haze levels which are critical to the earth's climate and habitability. This will provide early warning of changes caused by industrial and other human activities. Examples of this are the effect of long term haze on average temperature and thus growing season, and the effect of some high altitude chemical species on the upper to middle atmospheric zone which protects us from damaging UV solar radiation. Also, the global information on cloud heights and wind will aid aviation by providing a more complete basis for flight plans.

Accommodation Requirements

1. Physical Characteristics

The central component will be a 1.25 meter diameter f/2 receiving telescope and three or four lasers with associated detectors. Some IR detectors may have to be cryogenically-cooled. The lidar should be integrated with the Space Station since it is an evolutionary program in which modules will be added or replaced as technology develops. If the Space Station cannot attain the orbital needs (see below), a free flier lidar would ultimately be required when the technology becomes sufficiently advanced.

Detailed physical characteristics of a fully implemented lidar system are shown in Table 4.2.5-3. Table 4.2.5-3 is based on the assumption that the Space Station provides most of the cooling capacity and all of the power, data handling command/telemetry, and data storage needs. It also assumes the lidar transmitter/receiver subsystem is fixed to the Space Station which is oriented to give nadir pointing of the lidar. Adding separate pointing and tracking capacity to the lidar will increase its size, power, and weight requirements on the Space Station.

Given the lidar system of Table 4.2.5-3, the overall external dimensions are estimated as 3X3X3 (meters).

2. Power and Duty Cycle

The maximum power levels shown in Table 4.2.5-3 can be reduced by using less than the assumed 100% duty cycle or can be increased by operating both the Nd/YAG and CO₂ lasers simultaneously.

3. Orbit

Due to the rapidly decreasing sensitivity of lidar with altitude, a low earth orbit is necessary. Orbit inclination should be at least 60° to cover the more populous pollution - producing parts of the earth.

4. Data

The Space Station should provide a data selecting/compressing microcomputer such as the LSI-11 or equivalent. The resulting pre-processed data may be recorded at 500 Kbps, with on-board storage sufficient to hold data until dump to ground. Another approach will be to transmit the data via TDRS in a near-real-time basis.

5. Logistics

Materials will be periodically needed for maintenance, repair, and calibration. Any cryogenics and laser dyes must be periodically supplied.

6. Control

Operating periods will probably be under crew control, or at least crew over-ride.

7. Stabilizing and Pointing

Nadir pointing is needed with a stability of $\pm 1^\circ$ and knowledge of $\pm 0.25^\circ$.

Table 4.2.5-3. Maximum Accommodation - System Design Characteristics Summary

SYSTEM/ SUBSYSTEM	ITEMS	EACH	TOTAL MASS KG	DC POWER WATTS	TOTAL VOLUME LITERS
SOURCE	Nd-YAG /DYE CO ₂ PULSE	3 1	510 210	1870 3750	1080 330
RECEIVER	1.25M; F/2 SWING AWAY MIRROR	1	693	INTERMITTENT 35	4550
DETECTOR	SINGLE PMT DUAL PMT TRIPLE PMT DETECTOR PROCESSOR	1 1 1 1	4 8 12 12	35 70 110 60	2.8 5.6 8.4 18
C&DH	CDH UNIT	1	17	100	18
ELECTRICAL POWER & DIST	POWER DIST UNIT BATTERY HARNESS SET	1 2 1	10 44 85	10	8 30
STRUCTURE	OPTICAL SUPPORT COLD PLATES SHROUD/DOOR	1 3 1	70 18 85	INTERMITTENT 60	160
THERMAL CONTROL	RADIATORS MULTILAYER INSULATION SET PUMP VALVES TUBE, HEATERS SET COOLANT	2 1 1 1	60 30 70 50	200	300
CORRELATIVE SENSOR	A/R	A/R	60	INTERMITTENT 100	30
TOTAL			1990 (4375 LB)	2350 -Nd:YAG 4230 -CO ₂ PULSE	6541

Space Station Implementation Approach

The Space Station will provide the opportunity to pursue long-lasting (5 year) lidar missions with in-space re-supply of consumables (such as cryogenics and laser dyes), maintenance and repair (especially of lasers), and modification of the lidar system capabilities (mission modification). Mission modification will be possible by replacing one or more of the lidar's laser/detector modules or module pairs.

As indicated earlier, the attached (to Space Station) or integral mode of operation is easiest to implement and is thus preferred for at least the early lidar mission flights. In this case, the re-supply of cryogenic and laser dye consumables can probably be designed as a remote, crew - controlled shirtsleeve environment procedure. Replacement of laser or laser/detector modules will require EVA by the crew. However, such retrieved modules can then be refurbished by the crew inside the space station in a shirtsleeve environment. Such modules can then be re-used by the lidar.

The OTV or TMS should not be necessary for at least early lidar missions and perhaps for all of them.

The lidar system will probably have a dedicated microcomputer and possibly dedicated data storage, depending on Space Station capabilities and other commitments. In any event, the semi pre-processed lidar data can be telemetered to ground stations using the normal Space Station system.

The lidar mission schedule calls for five year-long missions starting in 1995.

Some advances in laser and related technology are needed before all of the desired lidar mission measurements/experiments can be performed. This is particularly true for wind measurements, which require a special CO₂ laser; and for daytime trace gas earth measurements in the visible spectrum, where a .0001 nm Nd: YAG laser output and .01 nm bandpass filters we needed. Also dye lasers outputs need to be increased in the 700-900 nm range.

Lidar mission logistics support includes the regular supply of cryogenics and laser dyes, plus the occasional supplying of new or different laser/detector modules.

Non-Space Station Implementation Approach

Without the Space Station, the lidar mission has been planned to operate from within the shuttle open bay. Thus while the Shuttle crew is available to remotely operate or override the lidar system, the missions must be short and no in-space replenishment or refurbishment is planned. Such operations are performed on earth between shuttle flights.

The data management system needs are the same for this approach as for the Space Station approach. If it is desired to pre-empt less of the Shuttle's data handling, power supply, and other capabilities, then a standard test rack has been conceptually designed to help out. While adding extra weight to the shuttle (at least 1000 kg), the test rack will fit in the shuttle bay with the lidar, and directly provide the needed power, thermal control, attitude information, and much of the DMS.

While the Shuttle version of a lidar mission may be flight ready slightly sooner than a Space Station version, the Shuttle missions will of necessity be short term and sporadic in nature. This will not provide the desired continuity of measurements. However, Shuttle flights will provide an ideal platform for proof-testing the lidar mission shortly before it is advanced to Space Station status.

Because the shuttle flights are short, there will be no significant lidar supply/refurbishment activities carried on in space.

Benefits Assessment

The greatest mission value benefit is the obtaining of long-term atmospheric measurements without long interruptions in data. This will greatly improve the usefulness of the data for determining the influence of human activities on our planetary environment.

The implementation advantages center around minimizing average cost for long missions. A long mission life with in-space re-supply maintenance, and even repair means less launch weight per year, and thus lower average cost per year as compared to sending the entire system up and down for many short Shuttle flights. The space station can be designed to supply needed power and most DMS functions. Again, the shirtsleeve environment will facilitate rapid

repair and/or modification of the DMS, as necessary. All these attributes together mean more mission effectiveness at lowest average cost.

Analysis Results

The Lidar Measurement of Air Quality mission is best implemented as an attached payload on a high inclination or polar orbit Space Station in order to obtain desired mission duration while providing frequent manned interaction.

4.2.6 ADVANCED OPERATIONAL METEOROLOGICAL SYSTEM

Description

The objective of this mission is to develop an improved operational system for the measurement of wind velocity, sea state, ice and snow cover, water vapor, precipitation, ground and atmospheric temperatures and other meteorological parameters, with the inclusion of search and rescue capabilities. The improved operational capabilities for the measurements will be based on new observational techniques and instrument concepts generated by cooperative technology development and research.

This is to be an improved version of current operational meteorological satellite systems, especially the polar-orbiting TIROS-N spacecraft and the geostationary GOES spacecraft.

It will carry improved versions of current instruments including SEM, AVHRR, AMSU, SSU, HIRS, S&R, ERB, SBUV, VAS, and WEFAX, as well as some newly developed instruments such as LIDAR, CZCS, LAMMR, ALT, SCAT, a lightning mapper, a solar x-ray imager, and separate imager/sounder. A conceptual mission configuration is shown in Figure 4.2.6-1. For the most efficient operation and the obtaining of the best results, a multi-satellite system is required with one being-polar-orbiting and two being geostationary.

Although there is, currently, an extensive global system of instrumentation including satellite-based instruments, the data base acquired through this system does not meet all needs. There remain vast areas of the globe, important regions of the atmosphere, and significant time periods for which no data are obtained. Further the resolution and the accuracy provided by the current measurement is, in some cases, not as good as needed for the applications - weather forecasting, etc. This mission will, with its improved

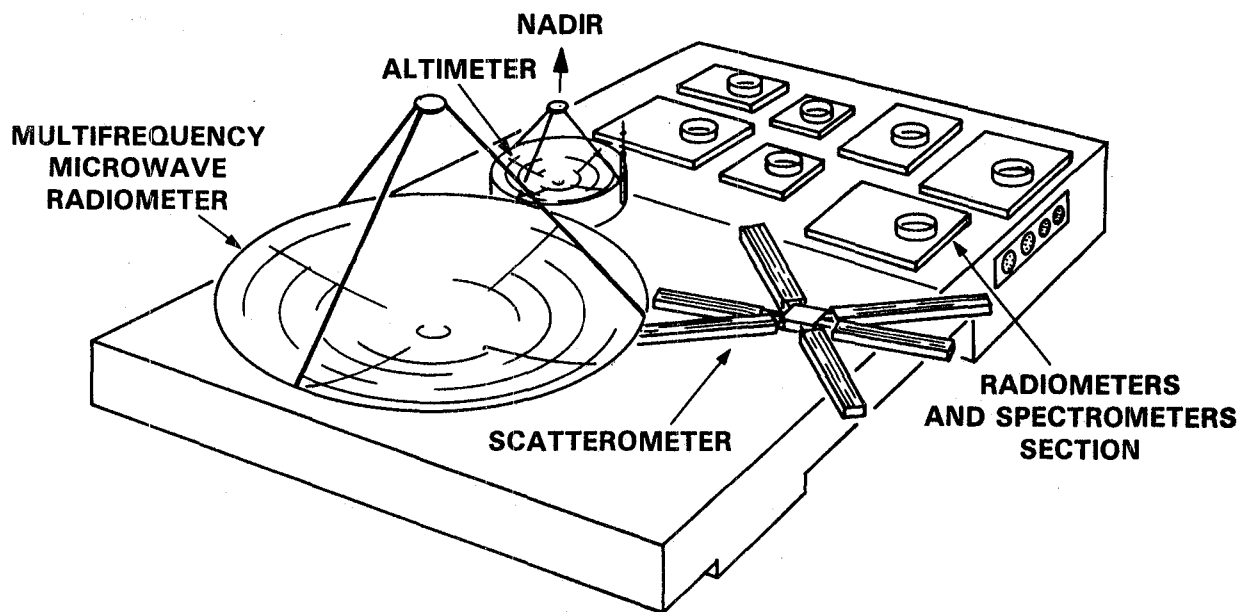


Figure 4.2.6-1. Instruments for Advanced Operational Meteorological System

and more complete instrumentation provide better and more extensive data as needed. Some improvements will be the ability to provide images and soundings simultaneously; better imaging resolution; finer horizontal and vertical temperature soundings; improved spatial and temporal imaging for severe storms; greater flexibility of location, area and timeliness of sounding; detection of lower energy plasmas; monitoring of electron flux density; and other improvements which will go far toward meeting user requirements.

The major instruments and their functions are shown in Table 4.2.6-1.. The instruments will be advanced versions of those listed here.

Operations during this mission are:

1. Installation of instruments on Space-Station, and calibration.
2. Checkout and calibration of instruments in geostationary platform.
3. Erection of antennas.
4. Launch from space station of spacecraft for geostationary positioning.
5. Activation of instruments.
6. Calibration of Instrument.
7. Data gathering.
8. Preliminary pre-processing.
9. Scheduled and unscheduled activation and deactivation of instruments.
10. Maintenance of instruments as needed.
11. Return of spacecraft from geostationary positions, servicing, and relaunching.

Table 4.2.6-1. Advanced Meteorological Sensors

AVHRR	High resolution radiometer	Sea Surface T, Ice, Snow, Cloud Cover
HIRS	IR Sounder	Atm. T and H ₂ O profiles
AMSU	Microwave Sounder	Atm. T and H ₂ O profiles
ERBI	IR Scanning and non-scanning radiometers	Earth radiation budget
SEM	Space Environment Monitor	Solar particles and X-rays, Magnetic field
SBUV	Scanning UV double monochrom	Ozone
ALT	Radar Altimeter	Altitude, winds, sea state, ice
SCAT	Radar Scatterometer	Winds
SSU	Stratospheric Sounding Unit	
VAS	Scanning Visible and IR	Atm. T and H ₂ O profiles. Cloud cover, cloud and surface T
S&R	Search and rescue	Emergency aids
LIDAR	Doppler meas. of aerosols	Winds
CZCS	Coastal Zone Color Scanner	Ocean Chlorophyll and turbidity
LAMMR	Multi-freq. Microwave radiometers	Sea surface T, Winds, ice Cover
Lightning Mapper Radiometers		Lightning

Selection Rationale

The Space Station could make valuable contributions to the Advanced Operational Meteorological System (AOMS), which is envisioned as a three-satellite system. One of these satellites will be in polar orbit, and since it is logical to assume that there will be a Space Station in a polar orbit, then that satellite could be "attached" to the Space Station. The other two would be in geostationary position.

Since the AOMS is an advanced version of current systems, there will be instruments aboard which will be flying for the first time. Thus there will be R&D testing required at the start which could benefit from the hands-on atmosphere of the Space Station since unexpected instrument configurational changes and procedures may be needed. Some of the instruments, such as SEM, require very clean optics and measurement surface. Regular cleaning is best accomplished by a crew.

Requirements of flexibility of target location, area coverage, and timeliness; while to some extent programmable or remotely accomplished, are more readily done by a capable crew.

These factors together with other maintenance, simple calibration, weight and power capability, payload reconfiguration capabilities, erection of antennas, and other obvious advantages of man's presence adds to the benefits of the Space Station.

Accommodation Requirements

Sensors requirements are given in Table 4.2.6-2.

Table 4.2.6-2. Sensor Requirements

	<u>Overall Dimension (m)</u>	<u>Weight (kg)</u>	<u>Power (w)</u>	<u>Data Qua. (Kbps)</u>	<u>Orbit</u>
AVHRR	.8 x .4 x .3	34	27	660	P
HIRS	.4 x .6 x .5	34	29	11	P
AMSU	.4 x .5 x .6	36	60	4	P,G
ERBI	.5 x .5 x .3	38	40	2	P
SEM	.4 x .4 x .2	7	5	1	P,G
SBUV	.6 x .7 x .4	30	20	1	P
ALT	1 x 1 x .7	200	177	11	P
SCAT	4 x .5 x .3	102	150	2	P
VAS	2 x 1 x .3	79	40	28000	G
S&R	1 x 1 x .2	45	100	24	P
CZCS	1 x 1 x .5	87	50	3440	P
LAMMR	4 x 5 x 5	322	156	60	P
LM	1 x 1 x 1	50	100	100	G

Orbit: P - Polar : 833 km. 98.7°
G - Geostationary

Space Station Implementation Approach

Some of the advantages in using Space Station in this mission are discussed above (Selection Rationale).

The mission is best carried out with the polar-orbit payload attached to Space Station and with the two smaller geostationary spacecraft (75° and 135°) launched from and serviced by Space Station. Before those launches any new R&D instruments could be tested in the Space Station.

Non-Space-Station implementation Approach

Without a Space Station this mission could be launched as a free flyer from the Shuttle. Antenna would have to be erected by shuttle personnel before the free flyer is placed in orbit. There would have to be regular visits by personnel brought up on Shuttle for servicing, bringing the free flyer back to Shuttle and relaunching it.

Benefits Assessment

The Advanced Operational Meteorological Systems will provide an enormous amount of data of both scientific and socio-economic value. The data of scientific value will provide information leading to the understanding of the meteorology of the atmosphere, which will ultimately lead to such advantages as better weather forecasting. Other data will provide more timely scientific results. There will be improvement in temperature profiles, surface temperature data, atmospheric moisture profiles, cloudtop height data. Wind data, fog maps, and lightning data, will be obtained operationally from the first time.

The capabilities and flexibility provided by the presence of man is significant. The immediate, capable actions often provides the difference between obtaining data of great value and that of little or no value. This is particularly true for many dynamic meteorological measurements which change or occur very rapidly, thus requiring similarly rapid response.

Analysis Results

The Advanced Operational Meteorological System should be implemented with an attached payload to a polar-orbiting space station and with two smaller payloads in geostationary position with service carried out by bringing the

geostationary spacecraft back down to the Space Station or by service at geostationary location supplied by the OTV.

4.2.7 TROPICAL METEOROLOGICAL SUPPORT MISSION

Description

The objective of this mission is to perform environmental measurements of the equatorial belt (from approximately $+30^{\circ}\text{N}$ to 30°S) that will support global meteorological measurements needed in climatological and weather investigations. This constitutes a new mission concept based on the premise that the initial station will be placed in a low inclination orbit such as the ETR-compatible twenty-eight degrees (28°).

The equatorial regions, particularly the oceanic areas have a large influence in the development of global weather patterns. The users, scientists as well as operational meteorologist, can make use of frequent and accurate data on vertical profiles of parameters such as atmospheric temperature, water vapor content, and precipitation. These measurements, coupled with surface temperatures and wind vectors will provide useful supplementary data to better understand the heat and mass exchange mechanisms as well as dynamic phenomena encountered in the equatorial belt and their effect on global weather.

The principal instruments and their functions are as follows:

1. Passive Microwave Radiometer - measures temperature, water vapor and precipitation.
2. Scatterometer - measures wind field vectors.
3. Pushbroom IR Mapper - earth surface temperature.

A conceptual mission configuration is presented in Figure 4.2.7-1.

Operations during this mission are:

1. Erection of the main radiometer antennas.
2. Checkout and calibration of the instruments.
3. Data gathering and pre-processing.

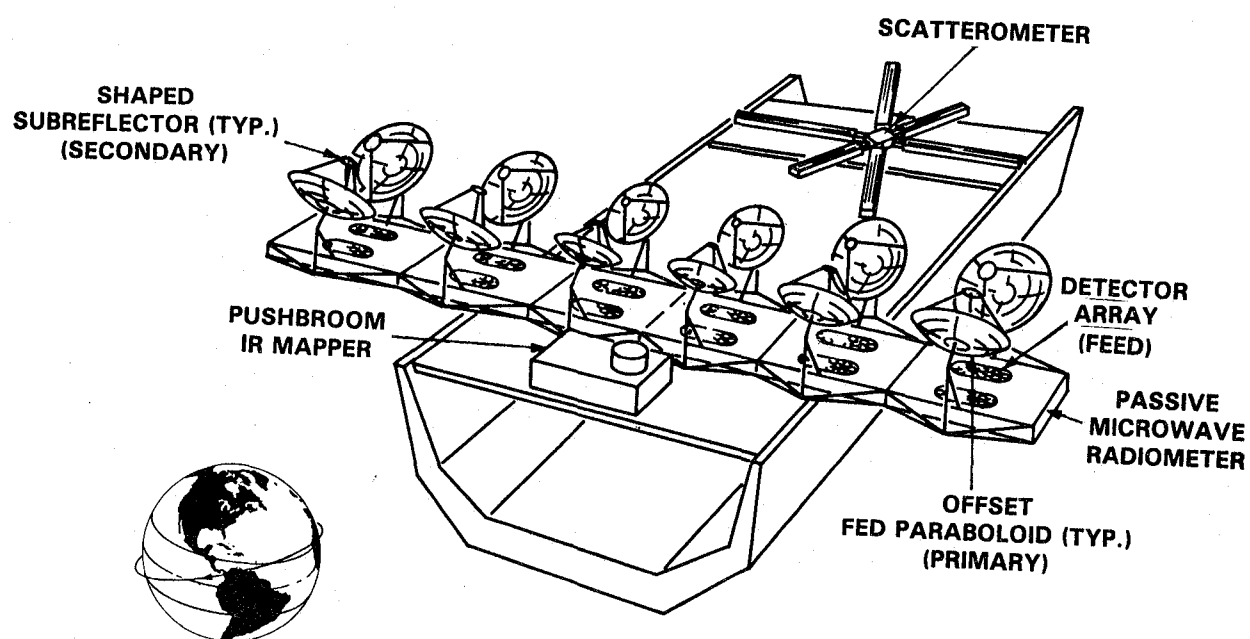


Figure 4.2.7-1. Sensor for Tropical Meteorology Support Mission

4. Control of the instruments by the crew.
5. De-activation of the instruments.
6. Reconfiguration of the payload package.
7. Maintenance of the payload.
8. Repeat of Steps 2 through 6.

The duration of one mission cycle (Steps 1-8) will be 4 years.

Selection Rationale

This mission was considered a promising candidate due to its high value in scientific and operational meteorology; use of the astronaut in the deployment of a large antenna assembly and in the maintenance, reconfiguration and control of the payload. In addition, its feasibility in a low inclination, low altitude orbit makes it a candidate for an early Space Station.

Accommodation Requirements

The characteristics of the sensors are given in Table 4.2.7-1.

Table 4.2.7-1. Sensor Characteristics

Sensor	Overall Dimensions	Weight	Power
Passive Microwave Radiometer	15x12x3M	500 Kg	300W
Scatterometer	(1M ³)	185 Kg	240W
Pushbroom IR Mapper	0.6x1.3x0.6 M	150 Kg	165W

The duty cycle of the sensors is approximately 90%, allowing for five "off" periods of one to three minutes each, per orbit.

The mission is compatible with altitudes up to 500 Km and inclinations 28⁰ to 35⁰. The total data acquisition rate is 5 Kbps for the Passive Microwave Radiometer, 6 Kbps for the Scatterometer, and 20 Kbps for the IR Mapper.

The stability of the instrument mounting interface is $\pm 1^0$. Angular rates should not exceed 0.01⁰/second.

Space Station Implementation Approach

The ability of the astronaut to perform the construction of a complex multifrequency antenna assembly will be a major attribute of use in this mission. The assembly contains twelve antennas, each featuring three elements: a primary reflector, a secondary reflector and a multi-element feed.

The recommended mode of implementation is "attached", wherein an unpressurized pallet or platform will mount all the instruments. Most of the electronics will be housed in the pressurized compartment, where the astronaut may monitor and control the data acquisition.

Technology advancements are required to develop the pushbroom, non-rotating passive microwave radiometer. On-going developments in multi-spectral linear arrays make it very likely that the IR Mapper technology will be available in time to support a 1990 launch. The scatterometer will be an advanced version of the Seasat Scatterometer, featuring six "stick" antennas for minimum wind-field ambiguity.

Non-Space Station Implementation Approach

If the mission were to be implemented as a free-flyer without the Station, the following will be necessary:

1. A larger payload, probably requiring a dedicated Shuttle launch.
2. A coupler deployment mechanism for automatic erection of the radiometer antenna.
3. Dedicated Shuttle sortie flights for reconfiguration and maintenance of the payload.
4. Higher resolution (e.g., 5 Mbps) multi-spectral pushbroom mapper, to permit ground control of the mission, based on earth surface observables.

Benefits Assessment

Although a quantitative assessment of benefits is not possible in this preliminary definition, there are significant benefits, namely:

1. Economic - through improved weather prediction, particularly relative to tropical storms.
2. Scientific - through improved information on atmospheric phenomena leading to enhanced weather and climate models.

The advantages of implementation in the Space Station are primarily related to transportation cost (placement and maintenance), higher reliability due to manned assembly in space, and diminished down-time due to repairs and unscheduled maintenance.

Analysis Results

This mission should be implemented as a Space Station attached payload for flight in the early 1990's. It will profit from the results of experimental and operational S/C and Shuttle flights in the next several years and from the technology development as noted above.

4.2.8 AURORAL MANNED OBSERVATION PLATFORM EXPERIMENT

Description

The mission objective is to provide both broad-view observation of nightside auroral phenomena (both northern and southern hemispheres), and selected detailed examination of various auroral features. This observation experiment utilizes a trained auroral scientist's selection of appropriate camera/other imaging systems. It can be part of a coordinated scientific effort utilizing the OPEN (Origin of Plasma in the Earth's Neighborhood) system of (4) satellites which are tentatively to commence operation in the late 1989-90 period. A mission concept is shown in Figure 4.2.8-1.

Selection Rationale

To date, detailed auroral observations in the visual wavelengths have been limited to ground-based "all-sky" photographs, sounding rockets and selected space-based imaging from the DMSP and Dynamic Explorer satellites. A systematic, space-based program of observation across the entire nightside of both auroral regions for a period of 90 days (typical space station mission)

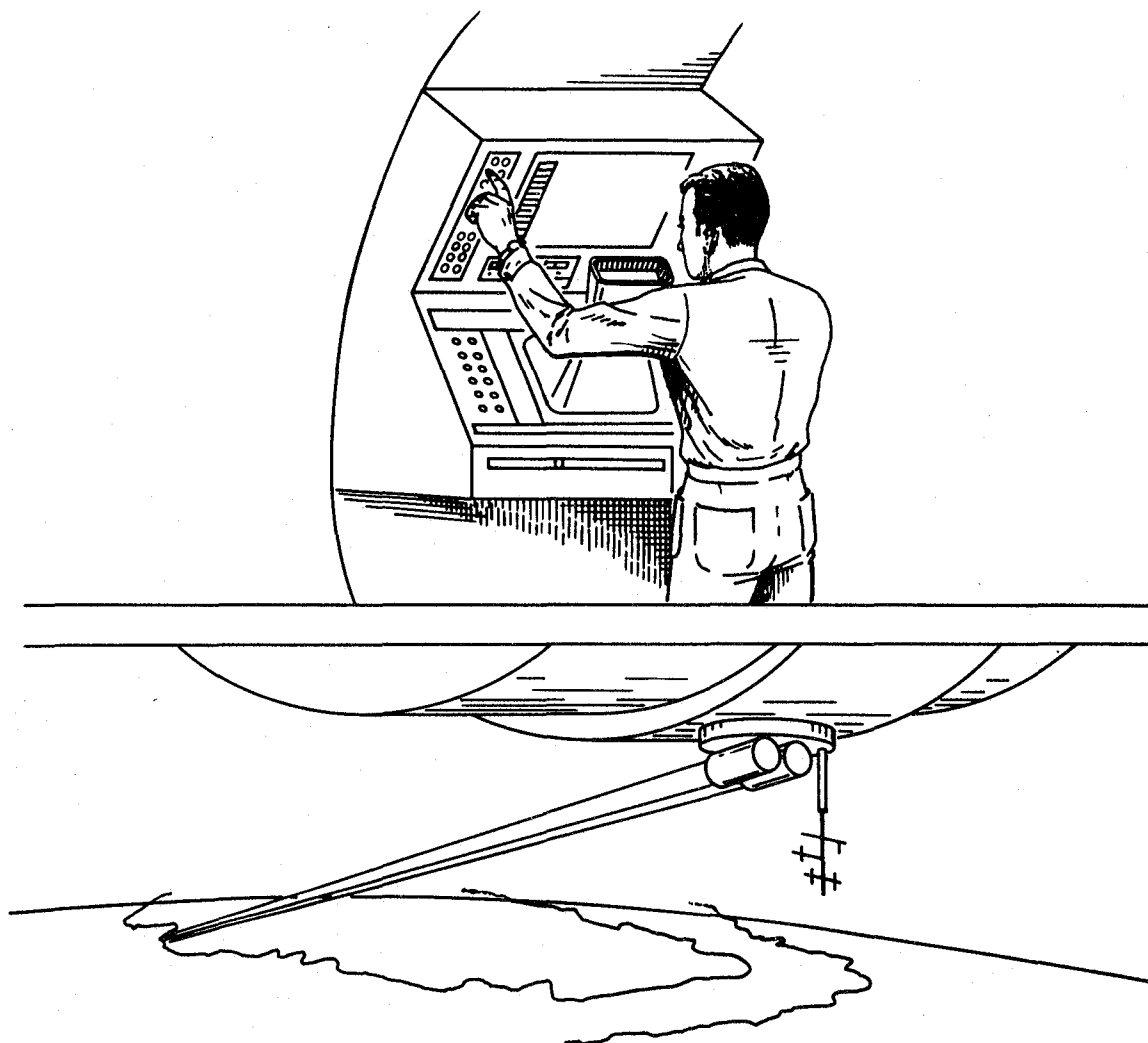


Figure 4.2.8-1. Auroral Manned Observation Platform

by a trained auroral scientist has never been attempted. This would possibly enable the discerning of, not only heretofore unknown auroral features, but also a unique synthesis of various known visual auroral features. A system of satellites designed to examine various physical aspects of the solar wind interaction with the earth's magnetosphere and ionosphere (which ultimately produce auroras) could produce an even greater synthesis of the overall solar-terrestrial physical linkage than from what is possible by the OPEN program alone. This is possible because the orbiting auroral scientist could utilize the near real-time information available from the OPEN satellites to further enhance the selection of the physically-related auroral features to be examined.

Accommodation Requirements

While visual nighttime auroras vary in intensity as a function of several physical parameters (such as geomagnetic substorm phase, solar activity, etc.), they are continuously being produced, and therefore their observation becomes a problem of availability on the part of the Space Station near/over the auroral regions (typically 60° - 70° north and south latitudes, at altitudes of 90-120 km). For this reason, an high inclination or polar Space Station orbit would be necessary.

The main mission equipment would include a steerable package of optical T.V. imaging systems and cameras (visual, UV, IR wavelengths) which can be operated by the orbiting scientist. Real-time TV images would be displayed to the orbiting scientist in conjunction with his own observations through a suitably placed optical viewing port in the Space Station. All TV images would be stored on mag-tape, and camera film would be periodically replaced. If the experiment is also to use near-real time data from the OPEN satellites, data access links from OPEN satellites to Space Station will be required. Main power requirements for the experiment will be related to the orbital time available over the auroral regions. Space Station stabilization and pointing requirements will probably be of the same order of magnitude as other comparable earth-viewing imaging systems (such as weather satellites).

Space Station Implementation Approach

Because visual aurora features can be rapidly fluctuating as a function of time (from seconds to minutes to hours) and position across the auroral zones, the advantage of having a trained orbiting scientist observing in real-time to

direct imaging systems at features of interest is obvious. While similar observations can be made by a Spacelab/STS scientist, the Space Station observer, who could be viewing for 90-day mission durations, would likely observe a far more complete range of features from various intensities of auroras than would be possible from a typical 7-day Spacelab mission. In addition, locating the experiment on the Space Station would allow for easy access for change of camera film and instrument repair/recalibration.

Non-space Station Implementation Approach

While it can be argued that a similar experimental system of auroral imaging could be performed by an unmanned spacecraft remotely directed by ground-based scientists, the rapidly-varying nature of auroral phenomena would tend to indicate that the reaction time in suddenly redirecting experiment systems towards a new target of interest would be a critical factor. Software programming in unmanned spacecraft to accommodate unexpected and rapidly varying experiment conditions is typically prohibitively expensive, and difficult to achieve. Indeed, a strong argument can be made that under such experimental conditions, the scientific discovery process can be best accomplished by having the coordinating scientist in the observer arena, which would be possible with the scientist in the Space Station.

Benefits Assessment

In terms of relative scientific, economic, and sociological merit, auroral phenomena not only affect ionospheric conditions which have a bearing on areas such as communications, but also are one part of the overall solar-terrestrial link which is believed to affect long-range climate changes on earth. Utilizing the experimental opportunity afforded by having an auroral scientist on-board would permit data gathering during unique experiment conditions, greatly enhancing the probability of new scientific discoveries.

Analysis Results

Implementation of this experiment can commence as soon as manned modules are incorporated in the Space Station. If similar auroral experiments are conducted on Spacelab/STS prior to the Space Station auroral mission, the Spacelab results/recommendations can be incorporated into the Space Station auroral mission planning. If the OPEN system of satellites is in operation during the same time period, near-real time access to that data source would further enhance the Space Station auroral mission results.

4.3 RESOURCE OBSERVATION

The single mission that has been selected to represent this discipline (Advanced E/R Sensing System) is designed to satisfy the requirements of the users in areas related to resource management and utilization. The observational requirements of this mission are a step-function higher than those in current systems such as Landsat D, particularly due to the higher spatial resolution and number of channels. An important feature of this mission that fits in very well with the capabilities of a manned Station is the flexibility of making changes on the primary instrument in order to optimize the data acquisition process.

4.3.1 ADVANCED EARTH RESOURCE SENSING SYSTEM

The Space Station would provide a more convenient assembly site than the shuttle and as such would certainly reduce cost. The proximity of trained personnel for repair and maintenance will also allow a lower cost design to be used. Finally, operators placed next to the equipment would provide a flexibility needed for commercial application.

Description

The objective of this mission is to act as a successor to the Landsat D series of spacecraft. The instrument payload consists of a Multi-Spectral Linear Array. It will provide high resolution imagery in the visible and IR with an integrated sensor system and consequently will support a wide range of geological and agricultural missions.

The emphasis will be upon a flexible response to user requirements. It will provide many bands of interest on demand through the manipulations of the technician aboard the Space Station who is operating the instrument. The instrument itself will be designed for maximum reliability and minimum development risk.

Requirements for a next generation earth observation spacecraft are well known. Kodak has conducted an eight month study for NASA in which it considered how the advanced requirements of users could be met in most credible fashion. The results were presented in the final report to contract NASW-3375 in December 1980 and at the 15th International Symposium on Remote Sensing of the Environment, Ann Arbor, May 1981.

Recent discussions with John Gabelman, private consultant and former Manager of Exploration Research at Utah International Inc., has uncovered the most useful mode of operation for earth resource companies. This mission will satisfy user needs for greater resolution. Requirements as expressed in NOAA document "Planning for a Civil Operational Land Remote Sensing Satellite System", June 20, 1980, indicated that the majority of users needed better than 30 m resolution in satellite imagery. The Thematic Mapper only satisfied the needs of 35% of the users polled because of this limitation. A 10 m resolution sensor would satisfy the needs of 94%.

Of greater significance, as Mr. Gabelman points out, commercial users will soon be in a position where they could specify bands of interest for specific locations.

An instrument that offered such flexibility would be a powerful tool. Commercial users would be far more interested in paying for such imagery tailored to their specific needs than more general mapping. Thus, there should be means for changing the filters determining the bands used in observation over a wide range of band centers and widths. The timing and area being observed should also be controllable. There, of course, is a continuing need for broad area mapping, as in now conducted by Landsat.

The sensor will generally provide imagery in the visible infra-red bands, including the following basic channels.

0.35 - .50 micron	}	visible
0.50 - .62		
.062 - .70		
0.74 - 1.0		
1.55 - 1.75	}	IR
2.10 - 2.40		
10.20-10.50		

Means for changing the filters which determine the bands will be provided.

Thus the principal functions to be performed aboard the Space Station are:

1. Receiving and inspection of integrated sensor system
2. System assembly
3. Testing, internal alignment and calibration
4. Mounting to Space Station with proper earth pointing orientation
5. Instrument operation from Space Station
6. Mapping mode will require minimum man involvement
7. Setting of filters (Upon demand)
8. Pointing the instrument to selected targets
9. Preliminary target assessments (annotated with the data and discussed with the investigator on the ground).
10. Selection of data and choosing of channel for transmission to ground.
11. Periodic re-calibration
12. Preventive maintenance
13. Corrective maintenance
14. Instrumentation upgrade
15. Sensor upgrade
16. Operations upgrade

Mission life of at least five years is desired. For mapping, monthly monoscopic coverage and bimonthly stereoscopic coverage will be satisfactory. Repeat access to a particular location can occur in two days.

Selection Rationale

This mission will provide mapping data to aid in planning world wide resource and food production. The flexibility that an on site operator provides enhances mission value substantially. The ability to mount the instrument system directly on the Space Station where it is easily accessible simplifies design, enhances overall reliability, and reduces cost. Remote operation would require a far more expensive and sophisticated instrument. Maintenance with repeated Shuttle flights would also be more expensive.

Accommodation Requirements

o Physical Characteristics

Multi-Spectral Linear Array Instrument

1.3 m x 0.6 m x 0.6 m 390 Kg

o Orbit (example of one candidate)

Sun synchronous, 9 - 11 AM equator crossing

Altitude	705 Km
Inclination	98.2°
Period	98.6 min
Ground velocity	6.74 Km/sec
Revisit period every 2 days	

o Data

300 Mb/s

Routing can be through TDRSS.

Space Station Implementation

The Space Station provides the first practical means for operating a truly flexible instrument in space. Direct operator control from the shirtsleeve environment of the Station is contemplated. With the sensor end of the instrument accessible from the Station, a human operator can vary filters, detectors and other system parameters at will so long as he has the requisite equipment. Since another filter or detector is likely to be small and light it can be brought up on the next Shuttle flight.

Since this instrument is a single integrated unit it can be easily transported to the Space Station and mounted with relatively low cost. The cost would be less than the design and construction of an independent spacecraft. The instrument could be tested, calibrated and modified in place, reducing the likelihood of failure.

Handling of the large data rate contemplated for this mission would also benefit from the presence of a trained operator who could provide on-board analysis of data quality and evaluations of image significance before transmission to earth.

Another capability could involve coverage of unexpected events. The operator could modify the instrument to measure the information sought. He could then select the site to be observed, and possibly during a single pass, train his instrument on the most significant aspect of the scene. The time of a single pass is sufficient for a trained observer to exercise such judgement.

Non Space Station Implementation Approach

The instrument could be mounted in a separate spacecraft after transportation by the shuttle. Operation would have to be from the ground as in Landsat. The flexibility of the mission would be severely curtailed and the spacecraft cost would be considerable.

Any change or modification of the instrument would of course require additional Shuttle flights. The size and complexity of the instrument would be greatly increased if the variability of the instrument is designed to be commandable and from the ground.

Benefits Assessment

This mission would provide high resolution mapping imagery of great importance to world food production and the discovery of depletable mineral resources. However, it could also satisfy a commercial need that will mature over the coming decade for imagery in specific bands in specific locations. The geological resources community is expected to be willing to pay for such a capability and users with agricultural interests are likely to as well.

The Space Station adds the flexibility attributes of the mission which will render it very effective. The basic mapping function could, of course, be accomplished in a free flying spacecraft but at higher cost and reduced reliability. The Space Station is suited for the mounting of a large integrated package.

4.4 LIFE SCIENCES

The major objectives of the NASA Life Sciences program are to understand and predict the effects of the space environment on humans, to develop the foundation for the extended presence of man in space, and to increase our understanding of the effects of the space environment on biological processes for the better understanding of life processes on earth.

The areas of concern for long-duration Space Station missions fall into three major categories: cardiovascular, musculoskeletal and hematology and immunology. Previous studies during Apollo and Skylab missions have surfaced serious medical questions in each of these areas. Missions on humans and animals are planned to address these concerns. Operational medicine missions will be concerned with the development of facilities, equipment and techniques for long-term crew health maintenance. Attachment B-1 of this Appendix describes a scenario of representative Life Science investigations that serve as background of the Space Station Missions contained in Section 4.4.

Fundamental questions in Gravitational Biology will be addressed on Biolab missions. The Space Station will provide the resources to support a shirtsleeve laboratory environment with the facilities for investigating gravitational effects on plant and animal development. The Biolab facility (Figure 4.4-1) is typical of a fully developed Life Sciences Laboratory.

4.4.1 CARDIOVASCULAR MISSION

Description

The objective of cardiovascular investigations is to resolve concerns about long term adaption or deterioration which is important for prolonged manned missions. Emphasis will be placed on fluid and electrolyte balance and its effects on the cardiovascular system, validation of the use of animal models for study of the human cardiovascular responses to weightlessness, cardiovascular adaption and possible deconditioning during long-term exposure to weightlessness, and changes in cardiovascular regulatory mechanisms and its effect on homeostasis.

The main elements of the proposed space station studies relate to long-term cardiovascular adaption. The time-course of adaptive changes will be followed in humans, primates and dogs through measurement of a large number of cardiovascular variables throughout the mission. In humans, the measurements will be made noninvasively both at rest and during provocative stress testing. In primates, the measurements will be continued in an extended-duration mission in order to help identify the factors that might cause irreversible cardiovascular changes with prolonged exposure to zero-g. In dogs, the measurements will include functional and structural changes of the cardiovascular system under weightless conditions. Taken together, the

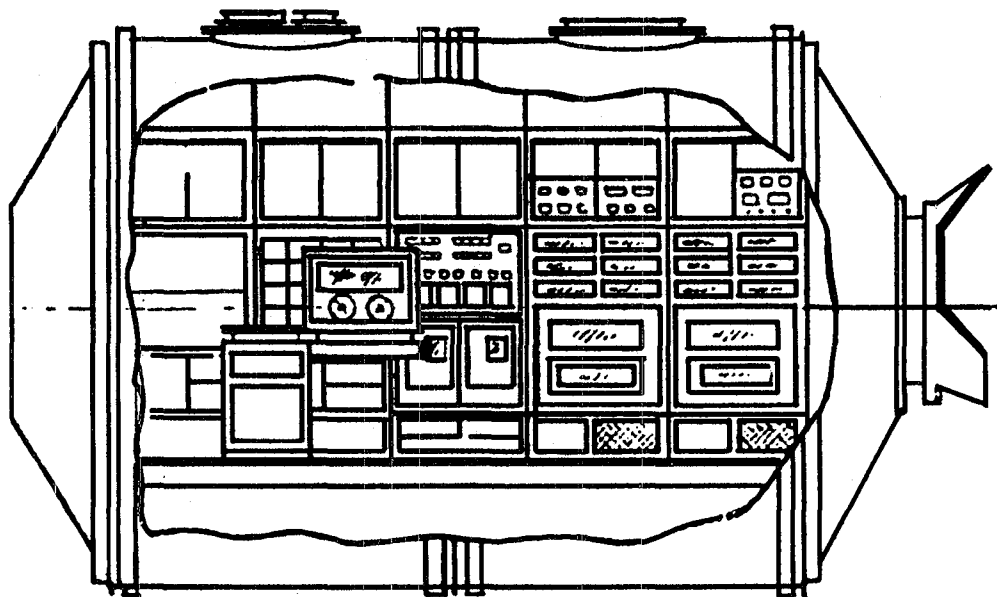


Figure 4.4-1. Life Science Laboratory Module

studies are aimed at providing a comprehensive knowledge of the mechanisms of cardiovascular adaption in zero-g. In addition to examining adaptive changes, the human studies are directed at testing the effectiveness of countermeasures in combating long-term cardiovascular deconditioning in zero-g. A large number of possible countermeasures exist, and even more are likely to be suggested during the coming era of frequent flights. As an example of a countermeasure study, a combination of saline ingestion and LBNP application is proposed, but it is suggested that the most appropriate countermeasures should be determined only after more data have been collected from the next decade of Shuttle flights.

Mission functions are:

1. On-orbit maintenance and servicing of equipment.
2. Downlink of housekeeping parameters and experiment data.
3. Crew to perform experiment operations, routine servicing of animal holding units and participation as test subjects. Crew training to laboratory technician level.
4. Periodic return of samples may be required.

The duration of each mission segment (humans, primates, dogs) should be at least 180 days starting in 1992.

Selection Rationale

No major impairment of cardiovascular function has been observed to date in space flights ranging in duration up to six months. However, functional cardiovascular abnormalities manifested as orthostatic intolerance and reduced exercise capacity have consistently been demonstrated in astronauts during the immediate postflight period. These manifestations, coupled with the fact that exercise capacity is maintained in space, suggest that the postflight cardiovascular dysfunction is the result of an appropriate adaptation to altered fluid distribution in zero-g, suddenly rendered inappropriate upon return to the 1-g environment. Although some factors involved in the adaptation process (blood volume loss, for example) have been identified, the underlying mechanisms are far from clear at the present time. A more pressing problem from an operational standpoint is the development of suitable countermeasures to offset the potentially debilitating effects of

cardiovascular deconditioning in zero-g. The long-term space station studies will provide an opportunity to fully address both these questions.

Accommodation Requirements

1. Maintain isolation between animal and human life support systems.
2. Equipment housed in a pressurized shirtsleeve environment.
3. Energy Requirements - 3000 watts average power.
4. Configuration - primarily rack-mounted hardware, mass - 3500 kg, 15M³ volume of rack space.
5. Maximum acceleration load - 10⁻³G.
6. Active cooling required.
7. Not orbit sensitive.

Space Station Implementation

Diagnostic equipment and animal holding facilities may be housed in a dedicated life science laboratory module, or, with suitable isolation provisions, in a general laboratory module.

Non-Space Station Implementation Approach

Animal experiments might be implemented using a space platform that would be visited periodically by the STS. Human experiments might utilize Spacelab in the STS sortie mode. The Spacelab/STS and platform missions each require compromises as compared to the Space Station mission. Spacelab/STS cannot provide long duration zero-g; it can perform long missions only in short pieces (typically two weeks). The platform mission provides long duration, but suffers from long periods with no crew presence.

Benefits Assessment

The cardiovascular mission is of direct benefit to achieving man's permanent presence in space. Space Station implementation provides long duration continuous manned interaction/participation at considerable savings in STS transportation costs as compared to STS sortie or STS-tended platform implementation.

better rodent countermeasures in a larger, upright animal. The human mission should confirm the results provided by the two animal studies.

Mission functions are:

1. On-orbit maintenance and servicing of equipment.
2. Downlink of housekeeping parameters and experiment data.
3. Crew to perform experiment operations, routine servicing of animal holding units and participation as test subjects. Crew trained to laboratory technician level.
4. Periodic sample return may be required.

The duration of each mission segment (human, primates, rodents) should be at least 270 days, starting in 1994.

Selection Rationale

Using classical balance techniques, calcium loss has been recorded in crewmembers from Gemini, Apollo, and Skylab missions, and very significant losses of muscle strength, muscle volume and total body weight have been noted during manned spaceflight. Composite studies of crewmembers from Skylab show calcium balance becoming increasingly negative from -50 mg/day in the second week to -300 mg/day about the twelfth week. Skeletal calcium loss has been partially confirmed by photon absorption densitometry which has recorded decreased mineral content of os calsis, distal radius, and ulna. Skylab studies of muscle strength and volume showed that leg muscle strength decreased nearly 25%, with a 5% decrease in muscle volume and weight during Skylabs 2 and 3, and muscle strength decreased 10% with a 2% decrease in muscle volume and weight during Skylab 4 with its more vigorous exercise program. A strong indication that the changes in muscle represent a breakdown of muscle tissue comes from the finding that nitrogen excretion exceeded nitrogen intake and there was a 35% increase in the excretion of 3-methylhistidine, a specific indicator of muscle protein metabolism. Nutrient balance studies are important tools in examining potential problems of weightlessness. In addition to the nutrient balance studies mentioned previously, Skylab studies showed there was also an excess excretion of sodium, potassium and phosphorous during flight. Only long-duration

spaceflights can establish whether muscle and bone atrophy continue indefinitely, or if there is an eventual adaptation.

Accommodation Requirements

1. Maintain isolation between animal and human life support systems.
2. Equipment housed in a pressurized shirtsleeve environment.
3. Energy Requirements - 3000 watts average power.
4. Configuration - primarily rack-mounted hardware, mass - 3200 kg, 13M³ volume of rack space.
5. Maximum acceleration load - 10^{-3} G.
6. Active cooling required.
7. Not orbit sensitive.

Space Station Implementation Approach

Diagnostic equipment and animal holding facilities may be housed in a dedicated Life Science laboratory module, or, with suitable isolation provisions, in a general laboratory module.

Non-Space Station Implementation Approach

Animal experiments might be implemented using a space platform that would be reunited periodically by the STS. Human experiments might utilize Spacelab in the STS sortie mode. The Spacelab/STS and platform missions each require compromises as compared to the Space Station mission. Spacelab/STS cannot provide long duration zero-g; it can perform long missions only in short pieces (typically two weeks). The platform mission provides long duration, but suffers from long periods with no crew presence.

Benefits Assessment

The Bone/Muscle/Metabolism mission is of direct benefit to achieving man's permanent presence in space. Space Station implementation provides long duration continuous manned interaction/participation at considerable savings in STS transportation costs as compared to STS sortie or STS-tended platform implementation.

Analysis Results

The Bone/Muscle/Metabolism mission should be implemented as an internal Space Station payload.

4.4.3 HEMATOLOGY AND IMMUNOLOGY

Description

Clarification of the dynamic events related to the observed decrease in red cell mass occurring during space flight is the basic objective of hematology experiments. Animal and human studies will be designed to improve the understanding of the effect of metabolic balance, erythroid stress and blood volume changes on red cell mass loss during spaceflight and the subsequent postflight recovery period.

A better understanding of immunological function during spaceflight requires animal and human experiments to determine the factors behind significant changes in lymphocyte responses to mitogens, leukocyte function and other significant immunological factors.

The dynamic events related to the observed decrease in red cell mass occurring during space flight are not well understood. The early missions are designed to improve the understanding of the nature of the changes that take place in the erythropoietic system and to assess the degree and time course of these changes during long-term space flight and recovery on Earth. The rodent and primate missions allow one to manipulate the system and to collect histological data that are difficult to obtain in humans. The human mission will not only establish a baseline of normal erythropoiesis regulation during space flight and confirm the results provided by the two animal models; it will also provide the information necessary to clarify the questions that have been raised during previous manned space flight: does the decrease in red cell mass represent an adaptation to a new zero-g related steady state, or is the decrease part of a transient response to the stress of space flight in which red cell mass will slowly return, during long-duration space flight, to its preflight value? The results from these experiments should also help to define the exact mechanisms involved in the decrease of red cell mass, regardless of whether the cause of the decrease is due to a reduction in red blood cell production caused by hemoconcentration, nutrition, decreased erythropoietin response, or other factors, or whether this decrease is due to

an increase in destruction caused by hemolysis, decreased red-cell half life, or membrane fragility.

The dynamic events related to the changes that take place in the human immune system during long-term space flight are not well understood. Therefore, it is important to accurately document the time course of any such changes in order to guarantee the immunocompetence of future crews involved in long-term space flight. The rodent experiments allow one to obtain tissue samples and to perform in vivo experiments that are either difficult or impossible to perform on humans. The human experiment will establish a baseline or normal immunological function during space flight and identify and significant changes that take place in the immune system. Based on the results of these experiments, further experiments may be required to ascertain the factors behind any significant changes in the immune system that may compromise man's ability to resist disease and infection during long-term space flight.

Mission functions are:

1. On-orbit servicing and maintenance of equipment.
2. Downlink of experiment data and housekeeping parameters.
3. Crew to perform experiment operations to test subjects, and service animal holding units. Crew training laboratory technical level required.
4. Periodic sample return may be required.

The duration of each mission segment (humans, primates, rodents) should be at least 180 days, starting in 1995.

Selection Rationale

A significant reduction in the circulating red cell mass in man has been consistently observed. Different mechanisms have been proposed for this decrease. The most recent data from human experiments support the concept that a suppression of erythropoiesis during flight is the major factor in the change. Some of the factors involved in red cell mass loss will be examined during Shuttle Spacelab missions. However, the exact etiology of this observed decrease in red cell mass is unknown, and the restrictions such a decrease might place on longer missions remain a matter of conjecture.

During early manned missions there was some evidence of alterations in plasma immunoprotein concentrations and the responsiveness of lymphocytes to mitogens. Skylab and early Shuttle missions also demonstrated postflight decreases in T-lymphocytes and T-lymphocyte function, leucocytosis, and a transient elevation in B-lymphocytes. Very little is known about the kinetics and function of leukocytes during long-term spaceflight. Therefore, to establish the immuno-competence of the crew-members, it is important to evaluate the changes in the immuno system that occur during long-term exposure to spaceflight.

Accommodation Requirements

1. Maintain proper isolation between animal and human life support systems.
2. Equipment housed in a pressurized shirtsleeve environment.
3. Energy Requirements - 3000 watts average power.
4. Configuration - primarily rack-mounted hardware mass - 3200 kg, 13M³ of rack space.
5. Active cooling of equipment required.
6. Maximum allowable G-load - 10^{-3} G.
7. Not orbit sensitive.

Space Station Implementation Approach

Diagnostic equipment and animal holding facilities may be housed in a dedicated Life Science laboratory module, or, with suitable isolation provisions, in a general laboratory module.

Non-Space Station Implementation Approach

Animal experiments might be implemented using a space platform that would be reunited periodically by the STS. Human experiments might utilize Spacelab in the STS sortie mode. The Spacelab/STS and platform missions each require compromises as compared to the Space Station mission. Spacelab/STS cannot provide long duration zero-g; it can perform long missions only in short pieces (typically two weeks). The platform mission provides long duration, but suffers from long periods with no crew presence.

Benefits Assessment

The Hematology/Immunology mission is of direct benefit to achieving man's permanent presence in space. Space Station implementation provides long duration continuous manned interaction/participation of considerable savings in STS transportation costs as compared to STS sortie or STS-tended platform implementation.

Analysis Results

The Hematology/Immunology mission should be implemented as an internal Space Station payload.

4.4.4 BIOLAB

Description

The BIOLAB mission concept provides a facility for the discipline of gravitational biology which includes those areas of life science research which address questions of fundamental biological significance not directly related to the major functional systems included in other disciplines such as cardiovascular systems, hematology, immunology, and musculoskeletal metabolism. Among the problems studied in gravitational biology are those that concern gravitropic and phototropic responses of plants, embryogenesis and organogenesis in animals, and animal and plant metabolism, and Controlled Ecological Life Support Systems (CELSS)

The goal of the CELSS experiments is to develop a food-regenerating biological life-support system using no external input except light energy. Several categories of investigation will be pursued: 1) the recycling of atmospheric gases and water; 2) the recycling of metabolic waste; and 3) crop-plant species selection.

The missions proposed for the discipline of animal developmental biology attempt to characterize the development of several species (rodents, frogs, etc.) in the absence of gravity. The following periods of development will be examined: (1) Conception to birth; (2) a single generation; and (3) multiple generations.

The missions proposed for the discipline of plant developmental biology attempt to characterize the effects of long-term exposure to weightlessness on

growth, structure, viability, reproduction, and responses of progeny. Experiments will be conducted on multiple species in order to evaluate whether there is a universal effect among plants.

The effect of weightlessness on metabolic activity in small mammals will be used to estimate energy requirements for animals and man in space.

Vestibular studies on animals will be used to determine the mechanisms involved in vestibular dysfunction and to improve countermeasures developed for the crew.

The purpose of CELSS missions is to provide important information on the effects of weightlessness on plant growth development and production. The knowledge gained in plant development studies will be used as a basis for CELSS experiments.

Species will be studied for their production of oxygen and their ability to convert nutrients into edible biomass. Nutrient cycling, gas exchange, productivity, and longevity will be characterized for candidate species.

The approach to the study of animal developmental biology is to conduct a series of missions in an order such that the results of each mission can be used to shape the subsequent mission. Each species studied should follow the same sequence: (1) Mission I - fertilization and cleavage, fetal development, birth; (2) Mission II - Conception/birth, postnatal development and maturation, aging; and (3) Mission III - first generation, higher generations. These missions, taken together, should be of significance to fundamental biology by increasing our understanding of basic biological processes and should have ultimate application in the assessment of the ability of man to colonize space.

Several species of plants will be studied to characterize the effect of weightlessness on plant reproduction and growth. The plants will be grown at several G levels in addition to 0-G. Mission I will determine the germination rate, structural development with the passage of time, reproduction rate, viability of seeds produced in 0-G. Mission II - production of generations, responses of progeny. These missions will provide insight into the

gravitational effect on development as a genetically or environmentally determined phenomenon.

The approach to the question of the relationship between metabolic rate and body size of adult mammals in the absence of gravity is to study on a long-term basis under inflight 1-G or 0-G conditions, metabolic rates of several species of small mammals under controlled conditions. Postflight studies will also be conducted for comparison with inflight measurements.

The mechanisms responsible for vestibular dysfunction associated with space flight are not understood. The early mission should provide data as to whether or not vestibular physiologic changes are involved, such as demineralization of the otoconia, and should determine the threshold and time course of these changes under various G levels. The non-mammalian and mammalian vestibular-function missions will serve to focus the assessment of this issue, based on the results of the early rodent mission, by providing data relevant to the sensory conflict theory and by furnishing information concerning the response of the vestibular system at various G levels in the initial, adaptive, and re-adaptive phases. By studying a variety of specimens it will be possible to observe the findings from lower through higher order animals. Results of these studies should allow eventual understanding of the human mechanisms involved with the subsequent refinement/enhancement of countermeasures and the development of better predictive indices.

The approach to the development of the CELSS is to utilize plant development experiments in conjunction with experiments on liquid and solid waste recycling and food regeneration. A pilot study of the development and productivity of dietary-useful higher plant crops grown in hydroponic cultures in weightlessness will provide the basis for the evolution of the CELSS.

Mission functions are:

1. On-orbit maintenance and servicing of equipment.
2. Downlink of housekeeping parameters and experiment data including video.

3. Crew to perform experiment operations and routine servicing of plant and animal holding units. Crew training to technician level required.
4. Periodic transfer of samples may be required.

The duration of each mission segment should be at least 180 days, starting in 1990.

Selection Rationale

Measurements on previous space flights have noted that, whereas there seems to be little or no changes in simple cell functions during and following weightlessness, there does appear to be a change in certain tissue and organ constituents in small animals. The origin of such changes is not clear, primarily due to a lack of appropriate controls for the experiments conducted. Exposure to radiation seems to have little effect on the development of lower life forms, but development in vertebrates is affected. In addition, embryological development in the frog has been studied with the experiments showing no effect of weightlessness on the frog's developmental processes. However, all data were collected using embryos which had undergone several cell divisions prior to launch and the studies are not conclusive. At this time, neither ground-based studies (in the centrifuge or clinostat), nor space-flight studies have clarified the role of gravity in embryological development. Long-term spaceflight experiments are needed to study development and reproduction.

Past studies in plant developmental biology in orbiting satellites (such as Biosatellite II), flight packages (Biostacks 1-3), and manned Spacelabs (Skylab 3 and 4) have noted deleterious effects of cosmic radiation on the plant and its reproductive system, and disorientation of both the gravity-sensing mechanism and the phototropic response to microgravity. Other short-term experiments slated for Spacelab 4 will explore the geotropic and phototropic responses in more detail. Results obtained from short-term experiments suggest behavioral adaptations to zero-g are due to physiological mechanisms; however, the gravity-sensing mechanism does not interfere with the accumulation of carbohydrates, and thus, growth. Because gravity may play an important role in the development of living organisms, especially with respect to the allocation and directionality of organs, and maturation and reproductive processes, it is necessary to carry out some long-term growth

studies. Particularly, as the organism develops, its exposure to microgravity should affect the structure and orientation of later-developing tissues and organs.

Manned space flight has revealed disturbances in the human vestibular system which manifest themselves through space sickness and disorientation. These symptoms occur in approximately 55% of crewmembers and last for three to five days. Two possible causes for these events are a sensory conflict between vestibular, visual and kinesthetic information and/or an inflight change in vestibular physiology.

Metabolism of mammals has been generally characterized as being proportional to the total body mass raised to the $1/2$ power. In further studies on active mammals maintaining erect posture, the proportionality factor changes the total mass to the $3/4$ power. Energy requirement in zero-g will decrease. Studies are required to establish the proper relationships using mammals, and to estimate man's energy requirements.

Accommodation Requirements

1. Maintain proper isolation of animal and human life support systems to prevent contamination of crew by the test specimens.
2. Equipment housed in a pressurized shirtsleeve environment.
3. Energy Requirements - 2 kw average power.
4. Configuration - primarily rack-mounted equipment mass - 3000 kg, 13.0 M³ of rack space.
5. Maximum allowable G-load - 10^{-3} G.
6. Active cooling of equipment required.
7. Not orbit sensitive.

Space Station Implementation

Diagnostic equipment, plant and animal holding facilities may be housed in a dedicated Life Science laboratory module, or, with suitable isolation provisions, in a general laboratory module.

Non-Space Station Implementation Approach

Animal and plant experiments might be implemented using a space platform that would be reunited periodically by the STS. The platform mission requires compromises as compared to the Space State mission; it mission provides long duration, but suffers from long periods with no crew presence.

Benefits Assessment

The Biolab mission is an important aspect of the Life Science program. There exists a family of basic problems in biology that are concerned with long-term observation of biological systems that are gravity-dependent. These studies will involve the utilization of the space laboratory environment to further the understanding of fundamental processes of biology, including those which are relevant to future medical research and long-term exposure of man to weightlessness. Space Station implementation provides long duration continuous manned interaction/participation at considerable savings in STS transportation costs as compared to STS sortie or STS-tended platform implementation.

Analysis Results

The Biolab mission should be implemented as an internal Space Station payload.

4.4.5 MEDICAL OPERATIONS

Description

The objective of the Medical Operations mission is to develop facilities to provide health care maintenance for the crew on long duration missions. The purpose of these facilities is to maintain the work efficiency of the crewmember performing increasingly complex work tasks for longer durations in a potentially hostile environment. Specific issues to be addressed are the following:

Is the healing process in weightlessness identical to that in one-g for skin lacerations, bone fractures, etc.?

Are the pharmacokinetics of drugs administered in space the same as those on Earth?

Which surgical/laboratory equipment must be specially designed to function in zero-g?

Accidents leading to trauma (skin breakage and bone fracture) will be among the most important medical considerations in space flight. As industrial tasks are added to the crew's duties, accidents producing crushing, punctures, and lacerations will become more common. There is no adequate characterization of tissue healing rates in zero-g, particularly for the bone and skin, tissues which are most susceptible to injury. The known alterations in calcium metabolism in zero-g suggest that bone healing may not be identical to that found in one-g. Healing of skin lacerations is governed primarily by physical forces (migration of fibroblasts and surface tension) and may not be expected to be changed in zero-g; however, this must be verified. Inasmuch as healing is preceded by an inflammation reaction, it is important to ascertain whether this process also is affected by gravity. Because bleeding usually accompanies trauma incidents, it is necessary to determine if clotting times are different in weightlessness. Consequently, three aspects of trauma will be studied in this overall experiment: bleeding and clotting, inflammation, and healing rates.

Once a disease has been identified and an appropriate medication has been prescribed and administered, the efficacy of that drug is dependent in large part on its concentration in the circulating blood. Pharmacokinetics refers to the process of drug transport from the site of ingestion or infusion of the drug to its site of action (e.g., specific or generalized cells or tissues). Knowledge of the pharmacokinetics of any drug forms the basis for predicting the dose-response and dose-frequency relationships. Four basic functions govern pharmacokinetics: absorption, distribution, metabolism, and excretion. Thus, anything which affects these functions will affect the efficacy of a drug. There is reason to believe that in zero-g, both absorption of certain substances from the gut and excretion are not the same as in one-g. Also, because body fluid volumes (including blood volume) are known to be reduced in weightlessness, the volume of distribution of any drug is reduced; consequently, its concentration is higher than it would be in a normal body fluid volume. However, pharmacokinetic studies using pharmacological agents have not been conducted during weightlessness. There is no need to test all drugs, but rather classes of drugs. For example, drugs may be classified on a pharmacokinetic basis according to whether they are actively excreted by the kidney, passively excreted by the kidney, or excreted by the lungs. The most important requirement for pharmacokinetic studies is a

means to monitor drug levels in blood. In the mission experiment included in this package, an example is provided for the study of absorption of an arbitrary drug.

A space-borne medical facility for prolonged habitation will include much equipment that is found in emergency rooms, doctor's offices, and small clinics. This will include examination, diagnostic, and therapeutic equipment (i.e., surgical instruments, biomedical monitoring equipment, imaging systems, examination kits, biochemical and microbial analysis kits, computers, and fluid infusion kits). Some of this equipment can be obtained from an off-the-shelf inventory without further modification for use in space flight. Other instruments may need to be designed and manufactured to withstand non-medical environmental hazards such as vibration, heat, and temperature. However, another class of medical equipment must be specially designed to meet the particular medical requirements of operations in weightlessness. Such items include fluid infusion equipment which cannot rely on gravity feed or gravity-induced air bubble elimination. Also, certain equipment concerning surgical procedures and blood containment may need to be redesigned, since fluids and unrestrained tissues behave quite differently in zero-g. The present mission objective addresses the design and evaluation of this class of medical equipment.

Mission functions are:

1. On orbit servicing and maintenance of equipment.
2. Downlink of experiment data and housekeeping parameters.
3. Crew to perform experiment operations and service animal holding unit.

The duration of each mission segment (human, primates) should be at least 30 days, starting in 1992.

Selection Rationale

The motivation behind a medical operations program is to maintain the work efficiency of the crews through health maintenance. Work activities will change from the present mix of flight testing, observing and experimenting in the Shuttle program to constructing, repairing, and manufacturing. The

medical conditions encountered will become more diversified. Typical medical problems which may arise are in the following categories:

1. Standard medical-surgical conditions of adults, e.g., infection, heart attack, kidney stones, etc., accidents (fractures, bruises, etc.)
2. Unique to space, e.g., space sickness, radiation, postflight conditions resulting from spaceflight, e.g., joint injuries, micro-fractures, postural hypotensions.
3. Psychological problems related to the isolated environment.

During Skylab and Shuttle programs, medical kits have been available to treat minor medical problems on an emergency basis. Long-term Space Station medical operations will require the development of a health maintenance facility.

Accommodation Requirements

1. Maintain proper isolation between animal and human life support systems.
2. Equipment housed in a pressurized shirtsleeve environment.
3. Energy requirements: 2000 watts average power.
4. Configuration - rack-mounted equipment for medical monitoring, surgical bench and equipment, mass 1500 kg, 10 M³.
5. Active cooling of equipment required.
6. Not orbit sensitive.
7. Crew training to laboratory technician level with at least one crewman a medical professional.

Space Station Implementation Approach

Diagnostic equipment and animal holding facilities may be housed in a dedicated Life Science laboratory module, or, with suitable isolation provisions, in a general laboratory module.

Non-Space Station Implementation Approach

Animal experiments might be implemented using a space platform that would be reunited periodically by the STS. Human experiments might utilize Spacelab in the STS sortie mode. The Spacelab/STS and platform missions each require

compromises as compared to the Space Station mission. Spacelab/STS cannot provide long duration zero-g; it can perform long missions only in short pieces (typically two weeks). The platform mission provides long duration, but suffers from long periods with no crew presence.

Benefits Assessment

The Medical Operations mission is of direct benefit to achieving man's permanent presence in space. Space Station implementation provides long duration continuous manned interaction/participation of considerable savings in STS transportation costs as compared to STS sortie or STS-tended platform implementation.

Analysis Results

The Medical Operations mission should be implemented as an internal Space Station payload.

4.5 MATERIALS SCIENCE

The objective of performing materials research in the space environment is twofold: (1) investigation of fundamental properties and processes that may impact ground based activities, and (2) identification of unique responses and capabilities that might be explored in space. Materials science aims at generic areas of interest without identifying specific commercial applications, with the expectation that some portion of the knowledge gained will lead to practical applications. Four areas of investigation are discussed in this section:

1. Thermophysical Measurements. Determination of high temperature properties of materials.
2. Undercooled Solidification Studies. Study metallic crystal and glass formations.
3. Chemical Reaction Studies. Formation of ultra-pure materials and refractory crystals.
4. Vacuum Vapor Disposition Studies. Deposition of thin semiconductor films in ultra high vacuum.

The first three areas can be addressed using the facility shown in Figure 4.5-1. The vapor deposition area requires a wake shield facility as described in Section 4.5.4.

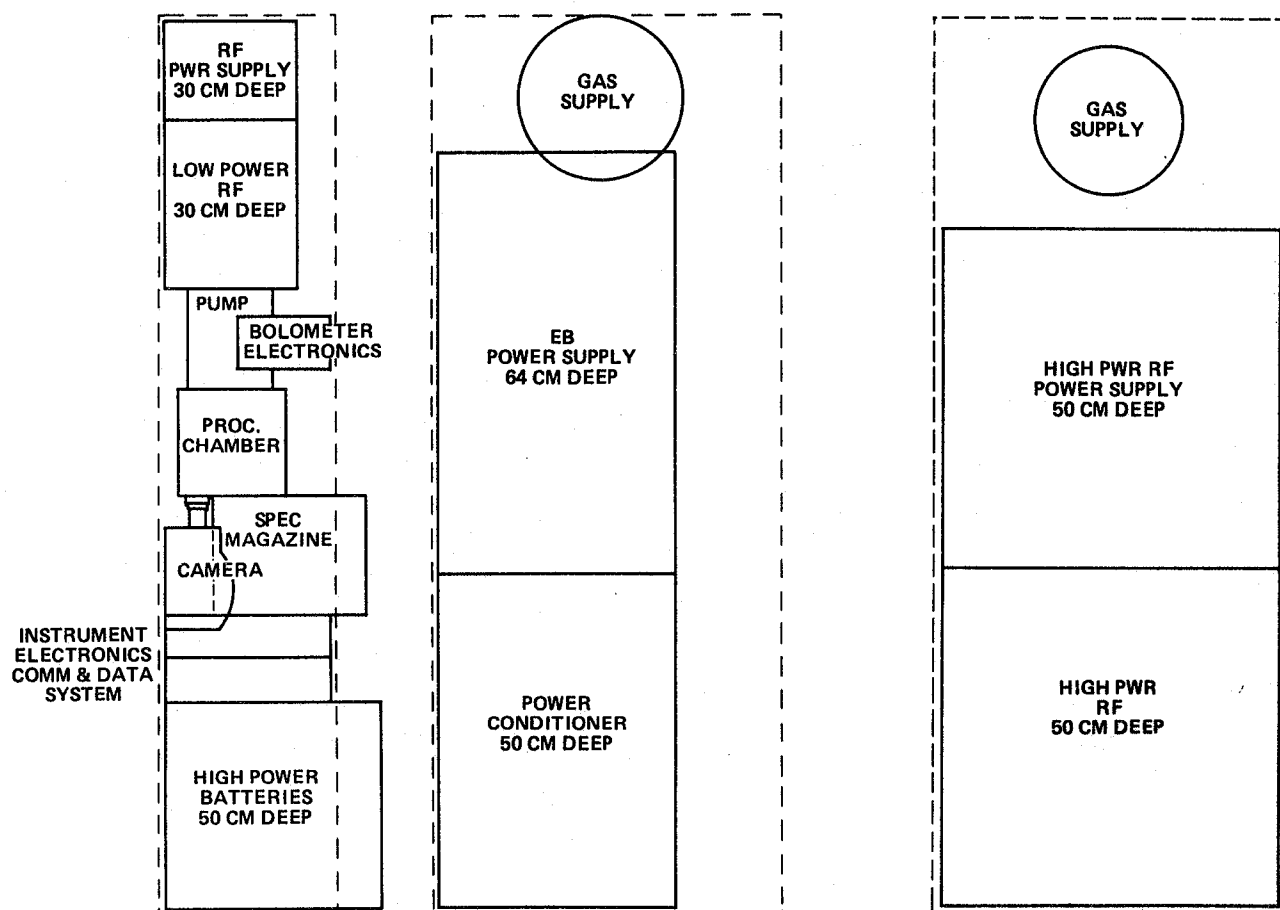


Figure 4.5-1. Materials Science Equipment Components in Standard Spacelab Rack

4.5.1 THERMOPHYSICAL MEASUREMENTS

Description

The mission objective is to determine high temperature values of specific heat, viscosity, thermal conductivity and vapor pressure for a number of materials of scientific and technical importance. This originates from the need to extend the work currently being carried out in ground-based laboratories to include high melting, poorly conducting, or high density materials for which no ground based techniques exist for the measurements. Space based techniques will allow the containerless melting, observations, and subsequent manipulation of such materials for which in-crucible techniques do not exist. Development of such techniques is presently being funded under the NASA MPS Program.

Experiment functions include deployment of free specimens in a vacuum or inert gas space without contamination, heating and melting using induction and/or electron beam heating and various subsequent properties measurement techniques. These may include deployment into a moveable calorimeter, observation of free cooling using pyrometry and bolometry, observation of rotational deformation of the free melt, and measurement of evaporation or deposition rates from the specimen. At least ten experiment cycles will be carried out on each of thousands of candidate material specimens. A measurement program lasting for at least several years is visualized with cleaning, repair, and refurbishment of the facility occurring at least monthly.

Selection Rationale

The rationale for measurement of important thermophysical materials properties using the microgravity space environment was reviewed favorably by the National Academies of Science/Engineering in 1976 and has since received considerable study by a NASA Science Working Group (Containerless Processing). It appears that microgravity offers solutions to the measurements problem for many materials for which earth-based techniques do not exist (primarily high melting, reactive materials).

Accommodation Requirements

The physical characteristics of the in-orbit environment required to carry out the mission have been reported from a previous NASA-funded study at General Electric (Final Report on Contract NAS8-33421, May 30, 1980). Although it

appears that such a mission can be initiated in sortie-mode using STS, the complete requirements for such a program in terms of equipment power and isolation for safety purposes appear to transcend STS sortie capability. Powers of 25 kw were proposed for missions to study certain materials to 4000°K, extension to additional materials and to needed temperatures of 5000 K will require powers of the order of 50 kw or more. The high power duty cycle is relatively short, usually no longer than a minute or two, with intervals between peak powers of 10 minutes to an hour or more.

For most missions, orbits and flight maneuvers which do not cause accelerations of the experiment facility by more than $10^{-4}g$ will be permissible. Later work to measure free cooling or surface tension over long time periods may require lower accelerations, such as could be provided in an internal detached facility or free flyer providing $10^{-7}g$.

It will be desirable to process most data on-board, since required experiment repetitions can be determined only through rapid feedback of processed experiment data obtained. Data will also be transmitted to earth for further processing; the bulk of data volume will consist of images of pre and post processed specimens, the latter including crude metallography photos taken in an on-board laboratory. 25 Mbits of information transmitted per day will probably be sufficient.

The data obtained will consist mainly of temperature-time data obtained from calorimeters or pyrometers, bolometer readings, deposition rate meters, gas pressures, equipment parameters and imagery and metallography of processed specimens. The post-experiment specimens also need be returned for detailed earth laboratory characterization. A few tens of kilograms of equipment repaired or replacement parts needs be delivered to the facility several times per year. Approximately 45 kg of inert gas will be consumed each month.

Semi-automated control of radio-frequency power and frequency, electron beam power, focussing and deflection, vacuum pumps and gauges, calorimeter actuation including thermal shutters, doors and thermometry. Deployment and recovery of specimens and choice of experiment parameters will involve considerable astronaut/technician participation, because the wide variety of materials and measurements will require corresponding variety in handling techniques and choice of experiment procedures.

Space Station Implementation Approach

This mission exploits the availability for man-equipment interactions in a shirtsleeve environment offering microgravity. It is assumed that peak powers of the order of 50 kw will also be available for periods of a few minutes at a time. Isolation of the facility during experiments at the highest powers and pressures, or to achieve lower g- levels will also be an attractive Space Laboratory option in later phases of the program. A crew of two working for eight hours per day can initiate such a program in the first year. Later the second crewman could be dispensed with except during repair periods.

This mission requires its own dedicated DMS and control system. An exception is for specimen image data which would benefit from integration with other Space Station image storage and transmission capabilities. All data (25 Mbits/day, mostly image information) will be transmitted to a ground station, preferably on a daily basis.

A rational schedule would include early conceptual experiments using a modified EML package during the early '80's, a 10 kw facility for STS in the late 80's, and the extended 50 kw facility for Space Station in the early 1990's.

A ground-based breadboard of the facility exists in terms of the joint GE/Rice/NBS experiment facility at Valley Forge, Pa. with the exception that control and data automation has not yet been accomplished. Further development into STS flight equipment in the 80's should provide smooth evolutionary development of the Space Station equipment.

Logistics support required: 10 kg/mo specimens and facility parts exchange for repair/replacement.

Non-Space Station Implementation Approach

As already mentioned, evolution of a low-power facility of limited capabilities will be extremely useful for initial research in the STS sortie mode. A pallet-mounted facility with controls located in the orbiter mid flight deck seems the most logical approach. Data would be stored and sent to earth except for real time processing of data for control automation. Development and use of an STS facility in the latter 1980's should be

possible, since ground-based activities are already underway. Logistics requirement similar to those described above for the Space Station facility.

Benefits Assessment

Economic benefits would stem immediately with the derivation of properties for molten reactive materials needed to improve a number of current industrial processes. This is evident to any engineer who has been disappointed in his search for some detailed properties, such as electrical resistivity for reactive molten materials for industrial process development, such as continuous electromagnetic casting or induction melting. High temperature properties for molten uranium oxide and other nuclear reactor materials are urgently needed to resolve reactor safety issues related to possible core meltdown, for instance. The economic impact of such improved safety assessments is some fraction of the total cost of nuclear plants worth several billion dollars each. The scientific benefit from an improved understanding of high temperature thermodynamic properties will be useful in areas such as planetary interiors and theoretical thermodynamics.

The additional benefit afforded by incorporation of a thermophysical properties measurement facility into the Space Station would be to open up possibilities for measurements at truly extreme temperatures: the example above of measuring reactor fuel properties at melt down type temperatures will suffice as an example. In addition there would be a much greater cost effectiveness in operation of the facility as compared to an STS sortie-type facility. The shirtsleeve environment with adequate technician availability would certainly multiply the effectiveness of such a facility by at least several times.

4.5.2 UNDERCOOLED SOLIDIFICATION STUDIES

Description

Objectives are the study of nucleation in undercooled melts, investigation of new metastable phases produced by undercooled solidification and production of bulk metallic glasses. Rapid cooling can also lead in some instances to single crystals of difficult-to-produce refractory materials.

Work attempting to achieve fundamental understanding of the solidification process by undercooling studies has been underway for many years in a number of laboratories. Elimination of heterogeneous nucleation provided by container walls has been a natural tool in such investigations. Containerless undercooling utilizing electromagnetically levitated melts has achieved limited success and it is natural to consider extensions of the technique possible in a microgravity environment.

The functions of the experiment apparatus are to provide contamination-free deployment of the material to be studied into a levitated position where it can be melted and subsequently cooled while being observed. Feeble positioning forces may be applied to prevent contact of the melt with surrounding objects to the extent that these positioning forces do not themselves cause nucleation. Temperature and total heat radiated, as well as surface features and recalescence, where this occurs, should be observed. Detailed post-solidification characterization by metallography, x-ray analysis, etc. may yield significant information regarding crystal structure or lack of order, chemical segregation, etc.

A heating/cooling cycle with a given material may involve minutes to tens of minutes. Environmental purification by gas flushing or vacuum pumping, and in-situ specimen surface cleaning may require times up to an hour per specimen. A continuous program studying a wide range of material compositions is envisioned.

Selection Rationale

Undercooling studies represent one of the most fundamental techniques for attempting to understand the solidification process. Some technical applications appear possible; e.g., bulk metallic glass has already been produced by slow undercooling.

Accommodation Requirements

Physical characteristics of experiment equipment needed for a modest STS sortie mission laboratory has been described in the final report to contract NAS8-33421, dated May 30, 1980. A Space Station expansion of such a facility would include provisions for astronaut/technician in-orbit modification of experiment procedures as provisional results from the experiments become available, just as is currently done in ground-based experiments. Achievement

and maintenance of ultra-clean conditions, necessary for avoidance of nucleation, in most instances would be provided by elaborate vacuum pumping equipment, inert gas flushing facilities. Handling and recovery of specimens, and some in-flight metallography on post-experiment specimens is required.

Five to ten kilowatts peak power will suffice for most experiments, the peak requirement lasting for only a few minutes except during vacuum system baking. One to several dozen cycles per seven hour working day might be typical. Availability of weak specimen position forces will allow use of any orbit providing less than 10^{-4} g acceleration.

A dedicated microcomputer should be provided for automated process control of many parameters. This data should be recorded for periodic (once a day) transmission to earth). The bulk of information content will comprise specimen images, including crude metallographic photos, totalling 25×10^6 bits/day.

Specimen size will range typically from 1 cm diameter to batches of small particles with diameters of perhaps 10 microns. These specimens must be returned to the earth laboratory for detailed materials characterization measurements.

Because provisional results of experiments will indicate desirability for new compositions for study in many instances, provisions should be made for rapid delivery to orbit (each week or month) of new specimen material. Replacement or repaired equipment components would also need to be exchanged.

Experiment parameters requiring measurement and control are outlined in the NAS8-33421 final report and include temperatures, pressures and gas analysis.

Space Station Implementation Approach

Useful Space Station attributes for implementing this mission are the hands-on interaction possibilities for rapid modification of experiment procedures based on early results obtained and the possibility for providing more elaborate provisions for ultra-high vacuum pumping, in situ specimen surface cleaning and observation, and more complete instrumentation. The facility would be located internal to the Station, as near as possible to the center-of-mass. A crew of two astronaut technicians for seven hours a day

would be desirable. Operation by of a single astronaut is possible provided another technician for equipment maintenance repair is available part time.

On-board data processing can utilize a central computer, although a dedicated microcomputer for control of process variables is desirable. Use of central data storage would be particularly useful for specimen image storage.

Present NASA MPS plans envision development of an STS version of the facility during the 1980's decade. Evolutionary development of the SS facility thus appears a natural possibility.

Non-Space Station Implementation Approach

STS sortie mode, as discussed above. Later work in a more quiescent environment (lower g) may require an unmanned free flyer.

Control would be semi-automated on-board, with frequent astronaut/technician command override and changes in experiment procedure. The latter requirements will be compromised in the STS sortie mode. But development of a less ambitious facility for the sortie mode can serve as the development program for the SS facility.

Benefits Assessment

The primary benefits will consist of increased scientific understanding of earth-based solidification processes, leading in some instances to improved earth-based technology. In a few cases, space production of high value amorphous materials or single crystals is a possibility.

A long-duration Station facility should be more cost effective in terms of progress of the scientific program, base on possibilities for immediate feedback of early results obtained. Availability of better vacuum/gas cleanliness and instrumentation would also make possible some experiments not possible in the STS sortie mode.

4.5.3 CHEMICAL REACTION STUDIES

Description

Mission objectives are the measurement of reaction rates and formation of ultra-pure compounds by containerless techniques. The work will emphasize

formation of compounds of highly reactive and refractory materials, including single crystals.

Some work in this area has already been funded under the NASA MPS program (Yale, MW Research Institute, Draper Lab), and ground based laser fluorescent diagnostic techniques are being developed. The mission addresses the need for fundamental studies of reactions and formation of ultra-pure materials which are normally compromised by crucible reactions.

The primary function of the experiment is the deployment, heating, and reaction of elements and combinations of elements in a levitated position, usually in a gaseous environment. The gas may participate in the chemical reaction with the suspended specimen. The material is then heated by induction or radiation heating, undergoes reactions, including compound synthesis, vaporization, or gas-surface reactions, is cooled and retrieved by non-contaminating remote manipulation. Gaseous species are identified and quantified by remote techniques, including mass spectrometry and laser fluorescent.

Preparation of the system for a reaction may require extensive vacuum pumping, baking, back fill with environmental gas, in situ specimen surface preparation over a period of an hour or several hours. The heating and chemical reaction normally will take place in minutes or tens of minutes. The experiment procedure will be repeated with compounds and gases of varying compositions, and under varied heating and pressure cycles. A continuous program requiring a year or more before major upgrading of experiment equipment is visualized.

Selection Rationale

The logic for selection of such a mission is the unique opportunity afforded by the microgravity environment to suspend containerless chemical specimens with entirely exposed, observable surfaces for extended period of time under controlled high purity conditions.

Accommodation Requirements

The experiment equipment requirements for this mission are only now being explored at Yale/MRI. A large CO₂ laser used for heating an aerodynamically suspended specimen is in process of being replaced by radio frequency induction heating more suited for in-orbit implementation. A dye laser

doubled to emit a tuneable ultra-violet line is used to excite fluorescence in the gas surrounding the specimen along a laser path grazing the levitated specimen. Automated optical spectroscopy, spatially resolved along the laser beam path, gives the distribution of atomic and molecular species along a traverse beginning at the specimen surface and ending at the cool wall of the reaction chamber. The measured distribution of these individual chemical species allows deduction of surface temperature, vaporization rate, diffusion rates, and in some cases chemical reaction rates. Other parameters requiring measurement are: heating power, specimen optical emission, mass spectrometric analysis of the environmental gas, and imagery of the specimen surface. Typical operating power would be 5 kw, 7 hours per day, with 10 kw of system heating power for outgassing of the reaction chamber once per day. Preparation for an experiment cycle may require up to an hour for gas and specimen cleaning, with the reaction cycle taking place in minutes or tens of minutes.

Any station orbit providing approximately $10^{-4}G$ acceleration will suffice for containerless suspension of the specimen by weak force fields with only small perturbation effects on the reactions studied.

Data needs to be recorded for transmission to earth on a once-per-day basis. Typical data consists of wavelengths and intensities of optical and mass spectrometer lines as a function of time, as well as specimen surface imagery. The latter will comprise the bulk of the experiment data, perhaps 25×10^6 bits per day. A dedicated microprocessor is required for automation of the bulk of experiment operations, with a keyboard accessible to the operator for variation of experiment procedure and process variables.

Output of the experiments is primarily experiment numerical data and post-processed specimens for later earth laboratory analysis. An on-board metallographic laboratory allowing some immediate analysis of specimen internal structure would also be great benefit to allow rapid feedback to the experiment cycle.

Space Station Implementation Approach

A Space Station implementation of the containerless chemical reaction facility would greatly increase the cost effectiveness of an extensive series of reaction experiments on a wide variety of chemical compounds and

semiconductors, as compared to a short-lived sortie mission implementation. The sophistication of the experiment instrumentation as well as the availability of higher power and greater time for vacuum preparation and system baking will also be beneficial.

The facility would be located internally in the Space Station. A crew of two astronaut/technicians would be required for initial shakedown and operation of the facility, on an eight hour per day shift. Later, one full time technician could be dispensed with, provided a second technician with maintenance/repair skills could be made available on perhaps a one shift per week basis.

Aside from the dedicated process control microcomputer, and recording of data for periodic daily transmission to earth, centralized storage of the bulk of the spectral and imagery data would be convenient. Dedicated displays and controls would be desirable. Ground station analysis of experiment data would lead to suggestions and requirements for new experiment procedures and parameters.

The technology for this mission is less developed than is the case for several other MPS science areas. Most of the 1980's decade will be required for establishment of an adequate earth based experiment discipline and definition of the class of experiments and associated apparatus details for in-flight experiments. Nevertheless, such a Space Station experiment facility can be considered for the early 1990's time frame.

Non Space Station Implementation Approach

Implementation of the chemical reaction studies facility in an STS sortie mode can be considered for the latter 1980's. Considerations of cost effectiveness may indicate that such a program be initiated in a Space Station rather than the STS sortie mode.

Benefit Assessment

The initiation of this mission should lead to significant new developments in understanding of chemical thermodynamics of high temperature, reactive systems where progress at present is hindered by lack of suitable crucible techniques. There is a possibility that technical advances could result from the preparation and study of ultra-pure semiconductor and other compounds where electrical or optical properties are determined primarily by impurities.

Although such a mission can be considered in the STS sortie mode, in-orbit availability would be rather short to amortize the large launch investment. It is also expected that for maximum cost effectiveness, considerable astronaut/technician participation in flight will be necessary to develop in-flight techniques to maximum effectiveness by allowing rapid changes in experiment procedures and specimen selection.

4.5.4 VACUUM VAPOR DEPOSITION STUDIES

Description

The objective of the mission is to explore new technology for deposition of thin semiconducting films in ultra high vacuum using the extremely high vacuum pumping rates in a wake shield facility. NASA-funded efforts have already shown that, in the best vacuum maintainable during vapor deposition in terrestrial experiments, crystalline semiconductor deposits can be laid down at much lower temperatures than when using chemical vapor techniques. This possibility, in itself, opens up new prospects for sequential processing of integrated circuits and other devices where presently the high (1000°C) required deposition temperatures destroy by diffusion any structures laid down previously. Other studies have shown that, in a wake shield facility, vacuum levels at least three orders of magnitude better than 10^{-10} during deposition could be achieved. On theoretical grounds, it is highly likely that such improvement over terrestrial techniques would lead to beneficial improvement in purity and freedom from defects for such semiconductor layers and devices.

Evaporation and deposition experiments would be carried out sequentially in a vacuum wake shield facility. Evaporation of a given material on a given substrate with controlled temperature would take place over hours or days. Subsequent cycles would expose different substrates and would in addition vary substrate temperatures. After several cycles, the source would be changed and evaporation devices cleaned and serviced. For cost effectiveness, the facility would be available in-orbit for at least one year at a time.

Selection Rationale

The theoretical rationale for improvements which may result from maintenance of ultra-high vacuum during vapor deposition of certain materials has been known for some time. In the last decade, NASA-funded and other studies have

verified this in the vacuum (10^{-10} torr) which can be maintained during practical depositions. But the purity of the deposited layers obtained under these conditions is poor, and orders-of-magnitude improvement using terrestrial pumps does not presently appear possible. The three-order-of-magnitude improvement (or more) achievable with a vacuum wake facility thus appears attractive. The importance of this technology in today's industry can be judged by the great emphasis being placed in the U.S. and particularly, Japan, on molecular beam epitaxy, the current jargon for these vacuum deposition techniques.

Accommodation Requirements

The main mission equipment for ultra-high vacuum vapor deposition studies has already been addressed under NASA-funded studies at General Electric, Bellcomm, Old Dominion University, McDonnell-Douglas, and the Langley Research Center. Sketches of sources, substrate mechanisms, and other equipment as it would be mounted in the wake shield can be found in the final GE report on contract NAS8-33121, dated March 31, 1980. This also shows the wake shield facility concept studied by McDonnell-Douglas Corporation. Figures 4.5.4-1, -2 and -3 show outline concepts of equipment components interfacing directly with the vacuum space as well as a typical power requirement profile for initial experiments. Note that the power required for shield outgassing has not been determined, but probably lies in the range of at least tens of kilowatts.

An experiment requirements data form can be found in the cited final contract report. Aside from sensors and other low mass, low power equipment, the main components are the shield outgassing power supply and heaters, the substrate storage racks, deployment and retrieval mechanisms, and vacuum shutter doors, the electron beam evaporation gun and power supply, and source mounts and deployment mechanisms. It is expected that novel evaporant sources allowing superheating of containerless materials will be developed for this purpose.

As a start, relatively low Space Station orbits can be utilized to achieve the 10^{-13} torr vacuum levels. Extension to even lower vacuum levels will be highly desirable, requiring higher orbits or co-orbiters which can be deployed and recovered from higher orbits.

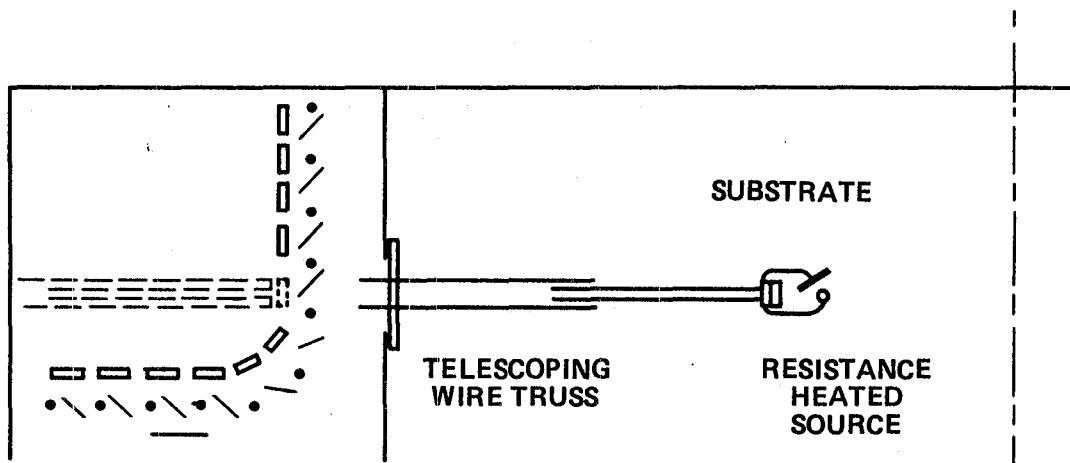


Figure 4.5.4-1. Substrate and Source Carousel and Deployment Concept

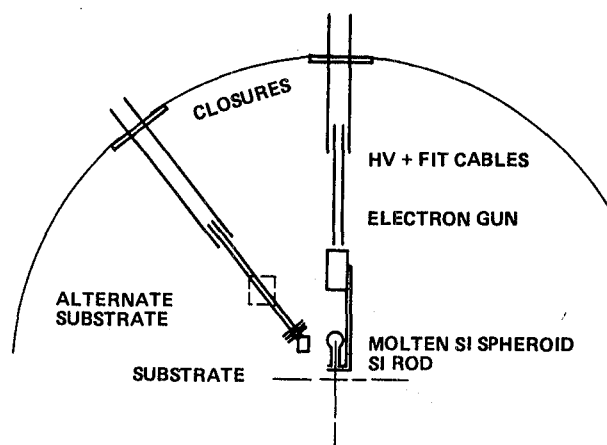


Figure 4.5.4-2. Molten Source Experiments

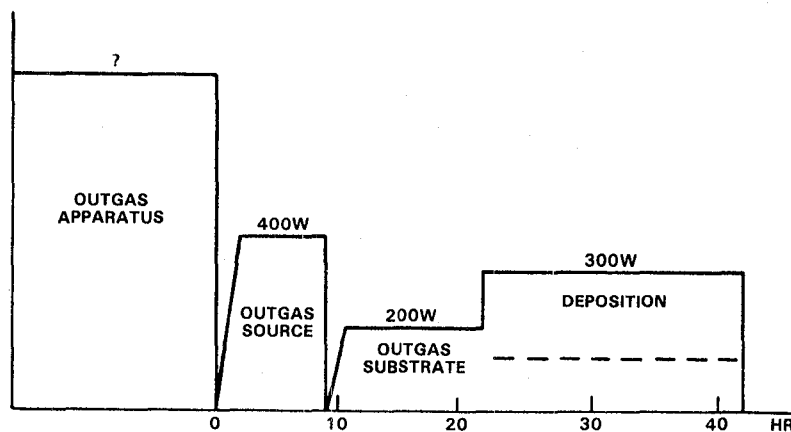


Figure 4.5.4-3. Experiment Power Time Line Excluding Hotel Load

On-board processing of data for experiment control is required. This data should also be stored for telemetering and further study on earth. Aside from temperature, pressure, and transducer outputs, imagery of sources, substrates, and deposits, including crude in-flight processed metallographic photographs will constitute the bulk of the information content. Twenty-five Mbits per day should be ample to cover these requirements.

The material output from the experiment will be substrates containing deposited layers of semiconductors or other materials (carefully protected from contamination), and depleted source material for subsequent analysis.

Logistics requirements comprise several tens of kg per month delivery and return of source and substrate material as well as spare, repaired, or replacement equipment parts.

Prime experiment parameters requiring control are: shield outgassing power, substrate deployment and retrieval motions, including vacuum doors, substrate temperature, source deployment and temperature, and control of auxiliary instrumentation and power sources.

The concave section of the wake shield must of course always be oriented in a direction to the rear of the spacecraft velocity.

Space Station Implementation Approach

The requirement of a vacuum wake shield evaporation/deposition facility may well exceed the projected capability of the STS sortie mode. This follows from the rather large investment in time and energy to outgas the shield, the outgassing power requirements, the necessity for frequent hands-on changes in source and substrate arrangement, plus the possible requirement for EVA occasional cleaning and decontamination of the shield, particularly when changing source material. As an alternate to cleaning the shield, installation of a new thin liner previously stored in a clean container can be considered. In any event, the wake shield must be located at a considerable distance (more than several hundred meters) from any manned vehicle in order to avoid contamination. This in itself calls for a co-orbiting free flyer probably more adapted to a Space Station than to a Shuttle sortie mission.

The wake shield must have its own dedicated data processing and automated control system. Other data should be processed aboard the Space Station and stored for periodic (once per day) transmittal for earth based recording and possible further processing. Twenty-five Mbits per day would be more than adequate to fill these needs, mostly imagery of sources and substrate metallographs. A minimal metallographic laboratory, consisting of specimen preparation tools, microscopes with photographic capability, and polarized photography should be available in the Space Station to support this and other Materials Science in Space missions.

Such a facility should be planned for the early 1990 time period. Reinstitution of the ground-based vacuum studies should be commenced immediately. In 1987, state-of-the-art molecular beam epitaxy equipments should be studied for upgrade and automation of source and substrate mechanisms for implementation of a Space Station facility in 1992.

Non-Space Station Implementation Approach

Implementation from a Shuttle sortie mode can be considered only if this mode is extended to include rendezvous with a wake shield free flyer over extended intervals of time, accompanied by maneuvers in the vicinity of such a free flyer, and if the degree of EVA permitted an enlarged astronaut/technician crew is significantly extended. Initial checkout of experiment techniques using the sortie mode for later Space Station implementation might be of interest and might deliver some useful scientific information.

Benefits Assessment

The economic impact of any significant improvements in semiconductor device technology, particularly for integrated circuits, would probably be at least at the billion dollar per year level. Because of the relatively insignificant mass of such devices, space transportation costs would be negligible, except for the research and possible production equipment. Although the increase in scientific knowledge would be significant, most materials research in semiconductors is today so highly applied that these would tend to be overshadowed by commercial values.

II/1/II

Successful implementation of a full scale program such as envisioned in this mission would require such a significant expansion of the STS sortie mode from that presently planned that it appears to correspond more nearly to at least a minimal Space Station concept.

ATTACHMENT B1
LIFE SCIENCES RESEARCH INVESTIGATIONS



ATTACHMENT B-1

This section contains a scenario of representative Life Sciences research investigations suitable for the Space Station. This material was prepared by G.E.'s Biomedical Research, Analysis and Planning Group within Management and Technical Services. The categories of investigations in the scenario are as follows:

- o Development Biology (Animals)
- o Developmental Biology (Plants)
- o Mammalian Metabolism
- o Life Support Systems (assessment in space environment)
- o Investigations Related to Biomedical Problems
 - Musculoskeletal
 - Hematological
 - Cardiovascular
 - Fluid Electrolyte
 - Renal-Endocrine
 - Vestibular
 - Immunological

LIFE SCIENCES
ISSUE SUMMARY SHEET

GRAVITATIONAL BIOLOGY

DISCIPLINE	ISSUE
DEVELOPMENTAL BIOLOGY (ANIMALS)	<p>Determination of the role of gravity in animal development, including:</p> <ol style="list-style-type: none">(1) Determination of the role of gravity in the process of fertilization, cleavage, embryo implantation, fetal development, and birth, with particular attention being paid to these events in mammals.(2) Determination of the role of gravity in postnatal development, maturation, and aging in a single generation raised in weightlessness from conception to natural death. Major areas of study should include the developmental stages of the major organ systems, the onset and development of biological rhythms, and the level and competency of sexual activity.(3) Determination of the effect of prolonged weightlessness on multiple generations of animals.(4) Determination of the ability of animals born and raised in weightlessness for one or more generations to readapt to the normal gravity environment of Earth.

LIFE SCIENCES
INTEGRATED MISSION SCENARIO

Issue: Determination of the Role of Gravity
in Animal Development

Category: Gravitational Biology/Developmental (Animals)

Background

Previous American and Russian space flights have noted that, whereas there seems to be little or no changes in simple cell functions during and following weightlessness, there does appear to be a change in certain tissue and organ constituents in small animals. The origin of such changes is not clear, primarily due to a lack of appropriate controls for the experiments conducted. In addition, embryological development in the frog has been studied with the experiments showing no effects of weightlessness on the frog's developmental processes. However, all data were collected using embryos which had undergone several cell divisions prior to launch and the studies are not conclusive. At this time, neither ground-based studies (in the centrifuge or clinostat), nor space-flight studies have clarified the role of gravity in embryological development.

MISSION LAUNCH DATE	MISSION NAME	MISSION OBJECTIVES	
1995 (1-month inflight study)	Rodent Fetal Study	1. Fertilization and Cleavage 3. Birth	2. Fetal Development
1997 (6-year inflight study)	Single Generation Rodent Study	1. Conception/Birth 3. Process of Aging	2. Postnatal Development and Maturation
1998 (1-year inflight study)	Multiple Generation Rodent Study	1. First Generation	2. Higher Generations

Mission Scenario Justification

Every major review of life sciences research in weightlessness has reached a conclusion not too different from the one that stated "... a study that would have great biological significance is one in which experimental animals would be reared from conception to maturation in a zero-g environment." These missions attempt to provide a definitive answer to the major question of development in the absence of gravity, at least for the rodent. The three missions examine development during (1) the period from conception to birth, (2) a single generation, and (3) multiple generations. This design is recommended in order that the results of each mission can be used to shape the subsequent mission, particularly since some probability exists that certain outcomes could lead to cancellation of all or parts of later missions, or to significant modification in protocols on these later missions. These missions, taken together, should be of significance to fundamental biology by increasing our understanding of basic biological processes both on Earth and in space, and should have ultimate application in the assessment of the ability of man to colonize space without artificial gravity.

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Determination of the Role of Gravity in
Animal Development

Category: Gravitational Biology/Developmental (Animals)

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Rodent Fetal Study	1. Fertilization and Cleavage. To determine whether mating and fertilization occur normally in the absence of gravity and to determine the effect of microgravity on cleavage, embryo implantation, and on primary axis formation.	1. Fertilization and Cleavage a) Activity and metabolic monitoring b) Mating/fertilization records c) Rodent sacrifice and embryo histological examination* d) In vitro fertilization and monitoring of rate and pattern of cleavage e) Comparative study of embryo development at various fractional gravity levels	Mouse Total Female: 168 Total Male : 45 56 females and 15 males maintained at: 0-g, 0.5-g, 1-g (control). Sacrifice Schedule: Embryo Histology: 8 Females/Day for 3 days from each group: 0-g, 0.5-g, 1-g. Fetus Histology: 8 Females/Wk for 3 weeks from each group: 0-g, 0.5-g, 1-g	Video equipment Sophisticated microscopes and micro manipulation equipment Mouse centrifuge - with holding facilities and video equipment	All of these objectives require a man-tended laboratory with controlled atmosphere, temperature, and lighting. This facility should be capable of supporting appropriate histological studies, observational studies, in vitro fertilization studies, long-term centrifugation studies, and be capable of housing the required number of rodents.
	2. Fetal Development. To determine the morphological consequences of weightlessness on the development of various organ systems, including the vestibular apparatus, the autonomic nervous system, the bone system, the muscle system, and the cardiovascular system. In addition, this study should examine the role that gravity plays in the morphogenesis of the highly asymmetric growing regions of the embryo to the asymmetric tissues and organs of the fetus.	2. Fetal Development a) Rodent sacrifice and fetal histological examination* b) Comparative study of fetal development at various fractional gravity levels *Detailed histological examination may be conducted on Earth.			

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Determination of the Role of Gravity in
Animal Development

Category: Gravitational Biology/Developmental (Animals)

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Rodent Fetal Study (Continued)	3. Birth. To determine the effect of weightlessness on normal parturition in rodents and particularly to verify that birth is possible without gravity.	3. Birth a) Video monitoring of events near parturition b) Observation of early postnatal nursing of the young c) Newborn pup sacrifice and histological examination* d) Observation of parturition events at various fractional gravity levels e) Return of live animals to Earth for subsequent examination	Sacrifice Schedule 12 newborn pups from at least 8 different litters from each group: 0-g, 0.5-g, 1-g. Return 12 pups from at least 8 different litters, but may be from same litters of above 0-g group.		
		*Detailed histological examination may be conducted on Earth.			

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Determination of the Role of Gravity
in Animal Development

Category: Gravitational Biology/Developmental (Animals)

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Single Generation Rodent Study	1. <u>Conception/Birth</u> . To verify previously collected data on rodent development from conception to birth.	1. Conception/Birth a) Activity/mating monitoring b) Video monitoring of parturition	Mouse Original Population Female: 30 Male : 10 First Generation ~ 180 mice Sacrifice Schedule 10 pups/week for 8 weeks of maturation These 10 pups are from at least 8 different litters.	Video equipment Mouse circulatory measurement devices Mouse centrifuge	All of these objectives require a man-tended laboratory, with controlled atmosphere, lighting, and temperature. This facility should be capable of supporting appropriate histological studies, observational studies, short-term (minutes to hours) centrifugation studies, and be capable of housing the required number of rodents.
	2. <u>Postnatal Development and Maturation</u> . To determine the effects of weightlessness on the continued development and postnatal function of the major tissue and organ systems, particular those related to the musculoskeletal system, the gravity perception system (including the vestibular system and portions of the autonomic system), the bio-rhythms system, and the sexual system.	2. Postnatal Development and Maturation a) Video monitoring of activity and function b) Physiological monitoring of temperature, blood pressures, and blood flows c) Stress testing in centrifuge for functional changes in various systems d) Rodent sacrifice and histological examination of musculoskeletal system, vestibular apparatus, heart and other major organs and tissues e) Monitoring of gametogenesis and level of sexual activity f) Return of live animal samples to Earth at various points of development to examine readaptation to 1-g.	Return to Earth: 10 pups/2 weeks for 8 weeks of maturation. These 10 pups are from at least 8 different litters. In addition, 1-g controls in space may be required for this experiment.		

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Determination of the Role of Gravity
in Animal Development

Category: Gravitational Biology/Developmental (Animals)

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Single Generation Rodent Study (Continued)	3. <u>Process of Aging</u> . To determine if weightlessness affects the aging process in rodents by examining various tissues and functions at different points during the entire life span of the animal.	3. Process of Aging a) Periodic observation and activity monitoring during the animal life span b) Periodic stress testing to ascertain functional changes occurring with age c) Periodic sacrifice and histological examination to determine time-sequenced tissue and organ changes	Sacrifice Schedule Original Population 6 mice/year until natural death First Generation 10 mice/year (~ 50% male, 50% female) Approximately 10 mice are followed to natural death.		

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Determination of the Role of Gravity
in Animal Development

Category: Gravitational Biology/Developmental (Animals)

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Multiple Generation Rodent Study	1. First Generation. To verify previously collected data on rodent development from conception to sexual maturity. To mate selected members of the population and monitor the birth of the second generation.	1. First Generation a) Selected monitoring of activity and function b) Selected physiological monitoring, stress testing, and rodent sacrifice with histological examination. c) Monitoring of sexual activity, mating, and birth of second generation. d) Return of Live Animal Sample to Earth at the beginning of the second generation to examine readaptation to 1-g.	Mouse Original Population Female: 10 Male : 5 Sacrifice Schedule: 10 sexually mature mice from different litters. Return to Earth: 50% of each generation born in flight returned to Earth alive after giving birth to next generation.	Video Equipment Mouse centrifuge Mouse circulatory measurement devices	All of these objectives require a man-tended laboratory, with controlled atmosphere, lighting, and temperature. This facility should be capable of supporting appropriate histological studies, observational studies, short-term (minutes to hours) centrifugation studies, and be capable of housing the required number of rodents.
	2. Higher Generations. To determine the effect of weightlessness on multiple generations of rodents. A minimum of four generations will be studied, but studies could continue to even higher generations.	2. Higher Generations For each generation produced in weightlessness, studies will parallel those conducted on the first generation. A sample of each generation will be returned to Earth for subsequent detailed studies of generational changes and readaptation to 1-g. On Earth, members of each generation will be mated and a study conducted of subsequent offspring.	10 females and 5 males will be selected from each generation to produce subsequent generation.		

LIFE SCIENCES
ISSUE SUMMARY SHEET

GRAVITATIONAL BIOLOGY

DISCIPLINE

ISSUE

DEVELOPMENTAL BIOLOGY (PLANTS)

Assessment of the role of gravity on plant growth, morphology, and reproduction, including an investigation of the following questions:

- (1) Is the response to zero gravity universal for all plants?
- (2) Is there functional impairment of any plant organs or systems during exposure to zero gravity?
- (3) Are there any changes in plant characteristics during several generations in weightlessness?

LIFE SCIENCES
INTEGRATED MISSION SCENARIO

Issue: Assessment of the Role of Gravity on Plant Growth,
Morphology, and Reproduction During Long Duration
Space Flight

Category: Gravitational Biology/Developmental Biology (Plants)

Background

Past studies in orbiting satellites (such as Biosatellite II), flight packages (Biostacks 1-3), and manned spacelabs (Skylab 3 and 4) have noted deleterious effects of cosmic radiation on the plant and its reproductive system, and disorientation of both the gravity-sensing mechanism and the phototropic response to microgravity. Other short-term experiments slated for Spacelab-4 will explore the geotropic and phototropic responses in more detail. Results obtained from short-term experiments suggest behavioral adaptations to zero-g are due to physiological mechanisms; however, the gravity-sensing mechanism does not interfere with the accumulation of carbohydrates, and thus, growth. Because gravity may play an important role in the development of living organisms, especially with respect to the allocation and directionality of organs, and maturation and reproductive processes, it is necessary to carry out some long-term growth studies. Particularly, as the organism develops, its exposure to microgravity should affect the structure and orientation of later-developing tissues and organs.

MISSION LAUNCH DATE	MISSION NAME	MISSION OBJECTIVES	
1994 (8 mos.)	Multispecies Plant Growth Study	1. Effects of Long-term Exposure 3. Reproduction	2. Effects of Short-term Exposure 4. Viability
1997 (12-18 mos)	Plant Multi-Generation Study	1. Production of Generations	2. Responses of Progeny

Mission Scenario Justification

Basic research and agriculture aside, the use of plants in space-flight research is an inexpensive tool by which to gather information on the developmental process in biology. In particular, experiments on multiple species can be performed at the onset of a series of missions, in order to evaluate whether there is a universal effect of zero-g among plants. An initial long-duration mission is desirable, in order to observe progressions in development for each plant species, and to study the aging process in weightlessness. An understanding of morphological changes in plant form leads to the questions of whether reproductive structures and functions can be carried out in zero-g, and ultimately, whether progeny (or seeds) can be produced. Thus, background information from the first mission should be available before carrying out a multi-generation study. The latter study is also long term, in order to accommodate time for several life cycles; it can provide insight into the gravitational effect on development as a genetically or environmentally determined phenomenon.

**LIFE SCIENCES
MISSION SUMMARY SHEET**

Issue: Assessment of the Role of Gravity on Plant
Growth, Morphology, and Reproduction
During Long-Duration Space Flight

Category: Gravitational Biology/Developmental Biology (Plants)

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Multispecies Plant Growth Study	1. <u>Long-Term Exposure</u> . To observe the development of various species of plants, all subjected to constant low gravity, in order to evaluate any universal response to long-term exposure to space flight.	1. Long-Term Exposure Wet all seeds Day-1 and maintain all plants and cultures at various levels of gravity for the duration of the mission. a) Monitor (inflight) growth with passage of time i. Germination rate ii. Dry weight iii. Cell counts (algae) b) Monitor (inflight) structural development with passage of time. i. Histological examination and photomicroscopy ii. Video monitoring	60 culture bags/plant trays each: <u>Ulothrix</u> (green algae) 100 plants per tray: <u>Lycopodium lucidulum</u> (club moss) 100 seeds per tray: <u>Triticum aestivum</u> (wheat) <u>Pisum sativum</u> (garden pea) <u>Helianthus annuus</u> (sunflower) Exp. 1: Divide 40 specimens into 4 gravity environments (0, 1/3, 2/3, 1-g) and sample several times first two weeks of mission and every 3-6 weeks thereafter. Exp. 2: At 20 times during the mission, including several days the first two weeks, expose one specimen to zero-g.	Algae growth bags and holding rack Zero-g holding units for plant trays Long-arm centrifuges to hold plants, set for 1/3, 2/3, and one-g. Dissecting and high power microscopes Video apparatus and housing Photomicroscopy apparatus Drying ovens and trays Balances sensitive to 0.1g.	Automated monitoring systems in plant holding units: light/dark cycles, temperature control, nutrient-watering. Laboratory space for 4 working crew several days, weeks 1 and 2 and less frequently thereafter.
	2. <u>Short-Term Exposure</u> . To observe the development of various species of plants subjected to brief periods of low gravity during discrete developmental stages, in order to assess the effect on plant organs grown from tissue differentiating at the time of exposure to low gravity.	2. Short-Term Exposure Wet all seeds Day-1 and maintain all plants and cultures at 1-g except when exposing each batch to 24-hours of zero-g at a discrete stage in development. Monitor as in (1) above.			

LIFE SCIENCES
MISSION SUMMARY SHEET

Page 2

Issue: Assessment of The Role of Gravity on Plant
Growth, Morphology, and Reproduction
During Long-Duration Space Flight

Category: Gravitational Biology/Developmental Biology (Plants)

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Multispecies Plant Growth Study (Continued)	3. <u>Reproduction</u> . To determine whether plants are able to reproduce in space flight, following either long or short-term exposure to low gravity, in order to assess whether natural progeny are produced.	3. <u>Reproduction</u> Observe processes of fertilization and pollination and monitor the production of seeds, if any, from mature plants grown in experiments (1) and (2) above. a) Histological examination and photomicroscopy b) Count seeds produced.	Mature plants <u>Pisum sativum</u> <u>Helianthus annuus</u>		
	4. <u>Viability</u> . To determine whether seeds produced in space are able to grow, in order to carry out further generation studies.	4. <u>Viability</u> Determine the percent germination of seeds produced in (3) above.			

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of the Role of Gravity on Plant Growth,
Morphology, and Reproduction During Long-Duration
Space Flight

Category: Gravitational Biology/Developmental Biology (Plants)

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Plant Multi-Generation Study	1. <u>Production of Generations</u> . To produce several generations of progeny from plants developed in low gravity, in order to observe whether the perception of gravity is manifested in similar ways throughout several life cycles of the plant.	1. Production of Generations a) Self-pollination studies (man-tended) b) Cross-pollination studies (man-tended).	<u>Pisum sativum</u> (garden pea)	Zero-g holding units for plant trays Long-arm centrifuges to hold plants, set for 1/3, 2/3, and 1-g Dissecting and high power microscopes	Automated monitoring systems in plant holding units: light/dark cycles, temperature control, nutrient-watering. Laboratory space for 4 working crew several days, weeks 1 and 2 and less frequently thereafter.
	2. <u>Responses of Progeny</u> . To observe characteristics and behavior of progeny from each successive cross, and to compare the degree of similarity of the responses to those of the parent plants, in order to determine developmental patterns and adaptability trends at different levels of integration in the plant.	2. Responses of Progeny a) Video monitoring of orientation and growth form. b) Histological examination and photomicroscopy of lignification and plant structures developed. c) Dry weight as measurement of growth.	10 times in each generation, sample plants growing at 4 gravity levels: 0-g, 1/3-g, 2/3-g, 1-g.	Video apparatus and housing Photomicroscopy apparatus Drying ovens and trays Balances sensitive to 0.1g.	

LIFE SCIENCES
ISSUE SUMMARY SHEET

GRAVITATIONAL BIOLOGY

DISCIPLINE

ISSUE

MAMMALIAN METABOLISM

Assessment of the effect of space flight on the basal metabolic rate of terrestrial mammals, including an investigation of the following questions:

- (1) Is the relationship between metabolic rate and body size of adult terrestrial mammals altered in the absence of gravitational loading?
- (2) Is the above relationship more noticeably altered after long-duration space flight than after short-term flight?
- (3) Is the postflight relationship between metabolic rate and body size similar to the preflight condition?

LIFE SCIENCES
INTEGRATED MISSION SCENARIO

Issue: Assessment of the Effect of Space Flight
on the Metabolic Rate of Mammals

Category: General Biology/Mammalian Metabolism

Background

Mammals characteristically maintain constant body temperature. Physiologically, this is related to metabolic heat production per unit of body surface area, combined with the energy required for motor activity and maintenance of erect posture. Mathematically, the results of laboratory studies find that total heat transfer rate through the body surface is proportional to total body mass raised to the $1/2$ power. But in actuality, further studies on active mammals find that the energy requirements for motor activity and maintenance of erect posture in Earth's gravitational field shift the proportionality to body size raised to the $3/4$ power. Theoretical and evolutionary considerations suggest that removal of gravitational loading should decrease metabolic energy requirements for motor activity and maintenance of erect posture; in space flight, the scaling of metabolic rate with body size is expected to be about the $1/2$ power. (This experiment is adapted from: N. Pace and A.H. Smith, The Physiologist, 24:S-37-S-40, 1981.)

MISSION LAUNCH DATE	MISSION NAME	MISSION OBJECTIVES
1998 (3-4 month inflight study)	Small Mammal Metabolism Study	1. Inflight Metabolic Rates 2. Postflight Metabolic Rates

Mission Scenario Justification

The relationship between metabolic heat production rate and total body mass for adult mammals is logarithmic, with the slope dependent on a scaling factor applied to body mass. In space flight, there is opportunity to examine the effect of weightlessness on the scaling factor. Several species of various sizes of mammals will be examined. (Interspecies variations in metabolic rate preclude the use of mice.) Each individual mammal will have reached the age at which metabolic intensity has stabilized. Musculoskeletal energy requirements are assumed to diminish with the duration in weightlessness. Thus, metabolic data should be collected on several occasions during the inflight period, in order to determine if the scaling factor does, indeed, decrease with time. After the mammals return to Earth, their motor activity and posture maintenance mechanisms will again be influenced by gravity. Thus, metabolic data should be collected during the postflight recovery period.

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of The Effect of Space Flight
on the Metabolic Rate of Mammals

Category: General Biology/Mammalian Metabolism

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Small Mammal Metabolism Study	1. Inflight Metabolic Rates. To determine the scaling of metabolic rate with body size during several months of weightless space flight, in order to assess the effect of gravity on mammalian metabolism.	1. Inflight Metabolic Rates Measure hourly metabolic rate (MR) each hour for five hours for each individual of each species after one week and at three monthly intervals. Maintain one control group and one test group. a) Monitor air inflow b) Monitor PO ₂ exhaust c) Monitor PCO ₂ exhaust d) Determine mean total body mass (TBM) for each species For each species, multiply the mean of the two lowest hourly values for O ₂ consumption by 4.85 to determine resting metabolic heat production rate (kcal/hr). Using the allometric equation $MR(kcal/hr) = 2.92 \times TBM(kg)^{.75}$, determine the power relationship per species.	6 controls each, 6 experimentals each: hamster rat guinea pig rabbit Age: 8-months old, preflight Reuse same individuals for each study. No sacrifices are necessary. Use all males or all females.	Cages for each individual animal, controlled with standard temperature and lighting. Experimental metabolic chambers, ventilated, with automatic monitors for O ₂ and CO ₂ . Centrifuges kept at one g, to hold all control mammals duration of mission. Racks for cages holding mammals at zero-g duration of mission. Centrifuged 'control' metabolic chambers, ventilated, monitored for O ₂ and CO ₂ . Large animal balance (10 kg \pm .5 kg capacity) Small animal balance (1 kg capacity \pm .05 kg)	Automated vivarium, weekly man-tended, for cleaning purposes.
	2. Postflight Metabolic Rates. To determine whether there is a return to the preflight terrestrial scaling factor for the relationship of metabolic rate to body size, in order to evaluate the effects of space flight on mammalian metabolism.	2. Postflight Metabolic Rates Repeat above studies soon after return to Earth, and one month later. Maintain same control group as above study.			

LIFE SCIENCES
ISSUE SUMMARY SHEET
OPERATIONAL SUPPORT

DISCIPLINE	ISSUE
LIFE SUPPORT SYSTEMS	<p>Assessment of the effect of space flight on system control of food regeneration from a photosynthetic and waste conversion process, including an investigation of the following questions:</p> <ol style="list-style-type: none"> (1) Do plants selected in ground-based research as favorable candidates for life support systems respond as favorably in zero gravity? (2) Can an entire life support system operate in zero gravity? (3) By what routes and rates do elements of liquid, gaseous, and solid wastes recycle in the plant? (4) During weightless space flight, where does the most nutritious biomass collect in plants selected for food regeneration studies?

LIFE SCIENCES
INTEGRATED MISSION SCENARIO

Issue: Assessment of the Effect of Space Flight on System Control of Food
Regeneration from a Photosynthetic and Waste Conversion Process

Category: Operational Support/Life Support Systems

Background

The development of a food-regenerating biological life-support system is a complex process of long duration, and follows from knowledge gained in earlier physiochemical regeneration-system developments. In order to realize the use of a food-regenerating support system in future space-station missions of long duration, it is necessary to first perform studies on ground-based homeostatically-controlled recycling systems. It is understood that ground-based studies on closed or partially-closed environmental systems will have been carried out well before the launch date of the first mission described below, and will have determined three or more candidate crop-plant species to be used in space flight. These species will be selected for their high production of oxygen and carbon compounds, consumption of CO₂, and their abilities to convert nutrients into edible biomass on Earth, under light, humidity, and temperature regimes easily governable in space flight. Plant development studies planned for early space-station missions will provide important information on the effects of weightlessness on plant growth, development, and production. As listed below, pilot studies concerning the controlled environment life support system (CELSS) should follow knowledge gained from studies in plant gravitational biology.

MISSION LAUNCH DATE	MISSION NAME	MISSION OBJECTIVES		
1995 (12 mos.)	Few Species-Liquid Waste Recycling and Food Regeneration Study	1. Nutrient Cycling 3. Productivity	2. Gas Exchange 4. Longevity	
1997 (12 mos.)	Few Species-Liquid and Solid Waste Recycling & Food Regeneration Study	1. Nutrient Cycling 3. Productivity	2. Gas Exchange 4. Longevity	
1999 (12 mos.)	Many Species-Liquid and Solid Waste Recycling & Food Regeneration Study	1. Nutrient Cycling 3. Productivity	2. Gas Exchange 4. Longevity	5. Food Preparation

Mission Scenario Justification

This scenario provides a pilot study of the development and productivity of dietarily-useful higher plant crops grown in hydroponic culture in weightlessness. Monitoring of each component in the above series of studies is expected to yield data on the capabilities of the progressively more complex waste media to support crops of plants, as well as to show how the plants, with respect to food regeneration, physiologically adapt to zero-g. The scenario assumes that the use of higher plants is more desirable for long duration and distance space flight than the use of perhaps unpalatable algae. Though animals will not be used as part of the food regenerated from the life support system, their exhaled CO₂ and excreted wastes may be considered as part of the system's input. Food preparation and intake is the final phase in the pilot study sequence and as such may signify successful operation of the life support system.

LIFE SCIENCES

MISSION SUMMARY SHEET

Issue: Assessment of the Effect of Space Flight on System Control of Food Regeneration from a Photosynthetic and Waste Conversion Process

Category: Operational Support/Life Support Systems

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Few Species - Liquid Waste Recycling and Food Regeneration Study	1. <u>Nutrient Cycling</u> . To trace pathways and turnover rates of mineral elements present in the liquid culture - waste water media and required by higher plants, in order to evaluate nutrient cycling behavior in zero-gravity and determine distribution of nutrients in the plant biomass.	1. Nutrient Cycling. Controls maintained at 1-g. Experimental systems maintained at zero-g. Macronutrients: C, H, O, N, P, Ca, Mg, K, S, Fe Micronutrients: Mn, Cu, Zn, B, Mo a) Daily monitoring of ionized macro and micronutrients in the liquid waste medium, using automatic analyzers. b) Perform tracer studies to follow the distribution and rates of movement of each macro and micronutrient through the liquid medium and plant, over a span of 1-3 days.	3 species or cultivars of crop plants, determined from ground-based studies. 2000 seedlings each, at start of mission, distributed to several sample compartments throughout the life support systems. Tracer studies will be carried out in individual compartments and will require crop harvests. Dry-weight (biomass) will be measured on entire crop contents of some remaining compartments.	Radioactive counter Water analyzers Gas analyzers Drying oven (60-70°C) Balances Zero-g maintained experimental controlled environment life support systems (CELSS), 2-3 m ³ , having several crop units, separate airways and hydroponic culture per unit, allowing for multiple monitoring experiments. 1-g maintained CELSS control, as above.	Laboratory facilities for cutting, drying, and weighing crop harvest, and for analyzing radioactive water, plant, and gas samples. Controlled environment life support systems (CELSS) to include: automated light/dark cycles, daily adjustment of pH (4-6.5), CO ₂ control (variable from 350-2000 ppm), humidity controlled at 70 percent, atmospheric pressure (14.7psi) solution conductivity maintained at 1/2-2X initial level, combination of cool-white fluorescent and incandescent lighting. Man-tended on occasion, in order to monitor and carry out experiments, propagate new crops, and keep pathogen-free.
	2. <u>Gas and Water Exchange</u> . To monitor pathways and turnover rates of metabolic and respiratory gases in the atmosphere, liquid culture medium, and leaf mesophyll/stomate system, in order to assess the operation of plant physiological mechanisms in the zero-g environment.	2. Gas and Water Exchange: CO ₂ , H ₂ O, and O ₂ . a) At weekly intervals during a crop life cycle, monitor the concentration of gases at all points of entry and exhaust in the system, day and night, using automatic analyzers.	New seed will be planted as each compartment is vacated.		

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of the Effect of Space Flight on System Control of Food
Regeneration from a Photosynthetic and Waste Conversion Process (Cont'd)

Category: Operational Support/Life Support Systems

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Few Species - Liquid Waste Recycling and Food Regener- ation Study (Continued)	2. Gas and Water Exchange (Continued)	2. Gas and Water Exchange (cont'd) i. Atmospheric inflow and outflow ii. Dissolved gases in liquid waste iii. Leaf mesophyll and stomate gas exchange b) On several occasions during the crop life cycle, monitor turgor pressure of the plant stem cells and leaf guard cells for each species or cultivar, during light and dark hours. c) Determine amount of water transpired (lg net production yields, generally, 150-600g H ₂ O) and transpiration efficiency (g net production: 1000g H ₂ O transpired).			
	3. Productivity. To determine the efficiency of the life support system with respect to oxygen released and edible biomass produced by plants in order to validate the use of a food regeneration system in zero-g on future missions.	3. Productivity a) At each harvest, determine for each species or cultivar the total and edible biomass (g) produced. i. Measure dry weight of edible parts and remainder of plant, beginning with initial harvest first week of flight. b) Determine net productivity by carbon fixation, using ¹⁴ C tracer study (experiment 1(b)).			

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of the Effect of Space Flight on System Control of Food Regeneration
From a Photosynthetic and Waste Conversion Process (Continued)

Category: Operational Support/Life Support Systems

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Few Species - Liquid Waste Recycling and Food Regeneration Study (Continued)	3. <u>Productivity</u> . (Continued)	3. Productivity (Continued) c) Determine oxygen produced, using ¹⁸ O tracer study (experiment 1(b)).			
	4. <u>Longevity</u> . To determine how long the system can maintain itself during space flight, in order to assess the degree of homeostatic control present and the degree of management required.	4. Longevity a) Record time for each species or cultivar to reach maturity. b) Record time taken for plant crops to produce edible biomass c) Determine how long system maintains itself.			

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of the Effect of Space Flight on System Control of Food
Regeneration from a Photosynthetic and Waste Conversion Process

Category: Operational Support/Life Support Systems

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Few Species - Liquid and Solid Waste Recycling and Food Regenera- tion Study	1. <u>Nutrient Cycling</u> . To trace pathways and turnover rates of mineral elements present in the liquified - waste water media and required by higher plants, in order to evaluate nutrient cycling behavior in zero-gravity and determine distribution of nutrients in the plant biomass.	1. Nutrient Cycling Controls maintained at 1-g. Experimental systems maintained at zero-g. Macronutrients: C,H,O,N,P,Ca,Mg, K,S,Fe Micronutrients: Mn, Cu, Zn, B, Mo a) Daily monitoring of ionized macro and micronutrients in the using automatic analyzers. b) Perform tracer studies to follow the distribution and rates of movement of each macro and micronutrient through the liquified medium and plant, over a span of 1-3 days.	3 species or cultivars of crop plants, the same as those used in first mission, if successful therein. Enough seedlings each crop to produce .5kg edible dry weight per man per day. Tracer studies will be carried out in individual compartments and will require crop harvests. Dry-weight (biomass) will be measured on entire crop contents of some remaining compartments.	Radioactive counter Water analyzers Gas analyzers Drying oven (60-70°C) Balances Zero-g maintained experimental controlled environment life support systems (CELSS), 2-3m ³ , having several crop units, separate airways and hydroponic culture per unit, allowing for multiple monitoring experiments. 1-g maintained CELSS control, as above.	Laboratory facilities for cutting, drying, and weighing crop harvest, and for analyzing radioactive water, plant, and gas samples. Controlled environment life support systems (CELSS) to include: automated light/dark cycles, daily adjustment of pH (4-6.5), CO ₂ control (variable from 350-2000 ppm), humidity controlled at 70 percent, atmospheric pressure (14.7 psi), solution conductivity maintained at 1/2-2X initial level, combination of cool-white fluorescent and incandescent lighting. Man-tended on occasion, in order to monitor and carry out experiments, propagate new crops, and keep pathogen-free.
	2. <u>Gas and Water Exchange</u> . To monitor pathways and turnover rates of metabolic and respiratory gases in the atmosphere, liquified culture medium, and leaf mesophyll/stomate system, in order to assess the operation of plant physiological mechanisms in the zero-g environment.	2. Gas and Water Exchange: CO ₂ , H ₂ O, and O ₂ . a) At weekly intervals during a crop life cycle, monitor the concentration of gases at all points of entry and exhaust in the system, day and night, using automatic analyzer.	New seed will be planted as each compartment is vacated.		

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of the Effect of Space Flight on System Control of Food Regeneration
from a Photosynthetic and Waste Conversion Process (Continued)

Category: Operational Support/Life Support Systems

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Few Species - Liquid and Solid Waste Recycling and Food Regenera- tion Study (Continued)	2. <u>Gas and Water Exchange.</u> (Continued)	2. Gas and Water Exchange (cont'd) i Atmospheric inflow and outflow ii. Dissolved gases in liquid waste iii. Leaf mesophyll and stomate gas exchange b) On several occasions during the crop life cycle, monitor turgor pressure of the plant stem cells and leaf guard cells for each species or cultivar, during light and dark hours. c) Determine amount of water transpired (lg net produc- tion yields, generally, 150- 600g H ₂ O) and transpiration efficiency (g net production: 1000g H ₂ O transpired.			
	3. <u>Productivity.</u> To determine the efficiency of the life support system with respect to oxygen released and edible biomass produced by plants in order to validate the use of a food regeneration system in zero-g on future missions.	3. Productivity a) At each harvest, determine for each species or cultivar the total and edible biomass (g) produced. i. Measure dry weight of edible parts and remain- der of plant, beginning with initial harvest first week of flight.			

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of the Effect of Space Flight on System Control of Food Regeneration
from a Photosynthetic and Waste Conversion Process (Continued)

Category: Operational Support/Life Support Systems

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Few Species - Liquid and Solid Waste Recycling and Food Regener- ation Study	3. <u>Productivity</u> : (Continued)	3. Productivity (continued) b) Determine net productivity by carbon fixation, using ^{14}C tracer study (experiment 1(b)). c) Determine oxygen produced, using ^{18}O tracer study (experiment 1(b)).			
	4. <u>Longevity</u> . To determine how long the system can maintain itself during space flight, in order to assess the degree of homeostatic control present and the degree of management required.	4. Longevity a) Record time for each species or cultivar to reach maturity. b) Record time taken for plant crops to produce edible biomass c) Determine how long system maintains itself.			

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of the Effect of Space Flight on System Control of Food
Regeneration from a Photosynthetic and Waste Conversion Process

Category: Operational Support/Life Support Systems

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Many Species - Liquid and Solid Waste Recycling and Food Regeneration Study	1. <u>Nutrient Cycling</u> . To trace pathways and turnover rates of mineral elements present in the liquified - waste water media and required by higher plants, in order to evaluate nutrient cycling behavior in zero-gravity and determine distribution of nutrients in the plant biomass.	1. Nutrient Cycling Controls maintained at 1-g. Experimental systems maintained at zero-g. Macronutrients: C,H,O,N,P,Ca,Mg, K,S,Fe Micronutrients: Mn, Cu, Zn, B, Mo a) Daily monitoring of ionized macro and micronutrients in the liquified medium, using automatic analyzers. b) Perform tracer studies to follow the distribution and rates of movement of each macro and micronutrient through the liquified medium and plant, over a span of 1-3 days.	10 species or cultivars of crop plants, determined from previous 2 missions and ground-based studies Enough seedlings each crop to produce .5kg edible dry weight per man per day. Tracer studies will be carried out in individual compartments and will require crop harvests. Dry-weight (biomass) will be measured on entire crop contents of some remaining compartments.	Radioactive counter Water analyzers Gas analyzers Drying oven (60-70°C) Balances Zero-g maintained experimental controlled environment life support systems (CELSS), 3-4 m ³ , having several crop units, separate airways and hydroponic culture per unit, allowing for multiple monitoring experiments. 1g maintained CELSS control, as above.	Laboratory facilities for cutting, drying, and weighing crop harvest, and for analyzing radioactive water, plant, and gas samples. Separate facilities for conducting dietary analyses. Controlled environment life support systems (CELSS) to include: automated light/dark cycles, daily adjustment of pH (4-6.5), CO ₂ control (variable from 350-2000 ppm), humidity controlled at 70 percent, atmospheric pressure (14.7 psi), solution conductivity maintained at 1/2-2X initial level, combination of cool-white fluorescent and incandescent lighting. Maintended on occasion, in order to monitor and carry out experiments, propagate new crops, and keep pathogen-free.
	2. <u>Gas and Water Exchange</u> . To monitor pathways and turnover rates of metabolic and respiratory gases in the atmosphere, liquified culture medium, and leaf mesophyll/stomate system, in order to assess the operation of plant physiological mechanisms in the zero-g environment.	2. Gas and Water Exchange: CO ₂ , H ₂ O, and O ₂ . a) At weekly intervals during a crop life cycle, monitor the concentration of gases at all points of entry and exhaust in the system, day and night, using automatic analyzers.	New seed will be planted as each compartment is vacated. Several untested or monitored compartments per week to be harvested for food preparation.		

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of the Effect of Space Flight on System Control of Food Regeneration from a Photosynthetic and Waste Conversion Process (Continued)

Category: Operational Support/Life Support Systems

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Many Species - Liquid and Solid Waste Recycling and Food Regeneration Study	2. <u>Gas and Water Exchange.</u> (Continued)	2. Gas and Water Exchange (continued) i. Atmospheric inflow and outflow ii. Dissolved gases in liquid waste iii. Leaf mesophyll and stomate gas exchange b) On several occasions during the crop life cycle, monitor turgor pressure of the plant stem cells for each species or cultivar, during light and dark hours. c) Determine amount of water transpired (1g net production yields, generally, 150-600 g H ₂ O) and transpiration efficiency (g net production=1000g H ₂ O transpired).			Galley should include means to prepare on-board grown produce.
	3. <u>Productivity.</u> To determine the efficiency of the life support system with respect to oxygen released and edible biomass produced by plants in order to validate the use of a food regeneration system in zero-g on future missions.	3. Productivity a) At each harvest, determine for each species or cultivar the total and edible biomass (g) produced. i. Measure dry weight of edible parts and remainder of plant, beginning with initial harvest first week of flight.			

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of the Effect of Space Flight on System Control of Food Regeneration
from a Photosynthetic and Waste Conversion Process (Continued)

Category: Operational Support/Life Support Systems

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Many Species - Liquid and Solid Waste Recycling and Food Regener- ation Study	3. <u>Productivity</u> . (Continued)	3. Productivity (Continued) b) Determine net productivity by carbon fixation, using ^{14}C tracer study (experiment 1(b)). c) Determine oxygen produced, using ^{18}O tracer study (experiment 1(b)).			
	4. Longevity. To determine how long the system can maintain itself during space flight, in order to assess the degree of homeostatic control present and the degree of management required.	4. Longevity a) Record time for each species or cultivar to reach maturity. b) Record time taken for plant crops to produce edible biomass. c) Determine how long system maintains itself.			
	5. Food Preparation. To prepare on-grown produce not needed for analysis, in order to supplement and add variety to crew diet, and to assess the culinary benefits of the life support system.	5. Food Preparation a) Develop cooking methods enabling retention of dietary requirements. b) Determine psychological acceptability c) Dietary analysis i. Proteins ii. Vitamins iii. Carbohydrates iv. Fats v. Minerals vi. Calories			

LIFE SCIENCES
ISSUE SUMMARY SHEET
BIOMEDICAL PROBLEMS

DISCIPLINE	ISSUE
METABOLIC RHYTHMS	<p>Assessment of disturbances in circadian rhythms of the fluid, electrolyte, and metabolic systems during space flight, including an investigation of the following questions:</p> <ol style="list-style-type: none">(1) What are the characteristics (i.e., mean level, period, amplitude) of the circadian rhythms of body temperature, plasma and urine electrolytes, and hormones?(2) Is there a shift in the normal circadian period as a result of exposure to weightlessness?(3) Do circadian rhythms become entrained to a new work-rest cycle?(4) Do circadian rhythms interfere with other physiological studies?

LIFE SCIENCES

INTEGRATED MISSION SCENARIO

Issue: Assessment of Circadian Rhythm Disturbances

Category: Biomedical Problems/Metabolic Rhythms

Background

The fact that many (if not most) measurable physiological quantities are not constant, even when tightly controlled, but exhibit a regular circadian rhythm about a mean value is well known. It is also known that extrinsic factors, such as noise, light intensity, vibration, or acceleration can modify the phase, mean, and/or period of the normal rhythm. For example, numerous changes in the rhythms of body temperature occur when animals are exposed to hypergravity produced by centrifugation. Rhythms may even be temporarily abolished following stress. Evidence from previous space flights is scanty regarding the effect of weightlessness on these rhythms. Data from primates (Bio-satellite) suggest that a change in period occurs for body temperature. On the other hand, human responses (Apollo) show no shifts in rhythms immediately after flight, but measurements during flight have not been performed. Aside from the fundamental scientific questions concerning the modification of circadian rhythms by weightlessness, there is a more practical problem of determining whether disturbing the normal circadian rhythms in space can interfere with the interpretation of physiological data collected inflight or alter the performance of crews working in space. Light/dark and rest/activity cycles are known to be potent synchronizers of circadian rhythms, and operational concerns dictate that work periods in space be shifted from the normal ground schedules. The ability to adapt to new work/rest cycles (measured by performance) and the ability of the pacemaker to entrain and resynchronize the body rhythms (measured by shifts in the circadian period, mean, or phase) is subject to high individual variations. It is important to assess these characteristics in the astronaut population.

MISSION LAUNCH DATE	MISSION NAME	MISSION OBJECTIVES
1991 (2-month inflight study)	Human Circadian Rhythm Study	<ol style="list-style-type: none"> 1. Characterize circadian cycles. 2. Effect of shift in work-rest cycle.

Mission Scenario Justification

These studies are designed to determine various characteristics of the normal circadian rhythms in the astronaut population, and to determine, by direct inflight measurements, whether weightlessness can produce alterations of the normal period of these rhythms. A study will also determine the separate effect of disturbing the work-rest cycle on the rhythms of physiological parameters. Measurements will be made of important quantities associated with body metabolism, including body temperatures, electrolytes, and hormones in the plasma and urine. Diet, light/dark cycles, and atmospheric conditions will be tightly controlled during the two weeks of intensive study. An additional study is proposed to test whether the diuresis of water loading can be delayed if the water load is administered in the "dark" phase. Such results have been found in primates in one-g.

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of Circadian Rhythm Disturbances
Category: Biomedical Problems/Metabolic Rhythms

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Human Circadian Rhythm Study	<p><u>1. Characterize Circadian Cycles.</u> To determine mean levels, period, and amplitude of biochemical and metabolic circadian cycles. To assess whether there is a shift in these rhythms as a result of exposure to zero-g.</p>	<p>1. Characterize Circadian Cycles</p> <p>a) Conduct study after two weeks of zero-g adaptation and repeat one month later.</p> <p>b) Controlled, constant diet for 7 days</p> <p>c) Measure void-by-void urine collections daily</p> <p>d) Sample blood 6 times daily on days 3,5,7</p> <p>e) Analyze blood and urine for hormones and electrolytes</p> <p>f) Body temperature measurements continuously for 24 hours on days 2,4,6</p> <p>g) Perform a fluid loading renal function test (i.e., consume 1.5 liters isotonic saline in 10 minutes, measure urine during the next 12 hours) at 12 noon and 36 hours later (12 midnight).</p>	Human 5 male 5 female	Body temperature electrode harness	These objectives require a man-tended laboratory facility with controlled atmosphere, temperature, and lighting. This facility should be capable of supporting biochemical analyses of urine and plasma.
	<p><u>2. Effect of Shift in Work-Rest Cycle.</u> To determine if normal circadian rhythms can become entrained to a shift in the work-rest cycle, and to determine the time course of this behavior.</p>	<p>2. Effect of Shift in Work-Rest Cycle</p> <p>a) Establish a work-rest cycle for the first month of space flight similar to the normal preflight pattern</p> <p>b) Shift the work-rest cycle by 6 to 12 hours and maintain for one month</p> <p>c) Repeat the measurements for Objective 1. during the last week of each month.</p>			

LIFE SCIENCES
ISSUE SUMMARY SHEET
BIOMEDICAL PROBLEMS

DISCIPLINE	ISSUE
MUSCULOSKELETAL (BONE)	<p>Assessment of the effect of space flight on bone metabolism, including an investigation of the following questions:</p> <ol style="list-style-type: none">(1) What are the primary initiating factors leading to the ultimate degradation of bone?(2) What is the nature of the effect of long-term space flight (6-18 months) on bone metabolism?(3) Are the effects of long-term space flight on bone metabolism reversible upon return to Earth?

LIFE SCIENCES
INTEGRATED MISSION SCENARIO

Issue: Assessment of The Effect of Space Flight
On Bone Metabolism

Category: Biomedical Problems/Musculoskeletal (Bone)

Background

Previous human calcium studies conducted during the Skylab flights have demonstrated that man continuously loses whole-body calcium throughout a flight duration of nearly 3 months. The cause of this loss is assumed to be directly related to the lack of gravitational stress on the bone itself, but the exact initiating factors are unknown. Some of these factors will be examined in future Shuttle Spacelab missions including the first life sciences dedicated Spacelab mission, SL-4. If the progressive bone losses do continue for the entire duration of longer space flights, then such losses may pose a threat either during such flights or upon return to Earth, both because of a possibly altered state of the calcium metabolism system and because of weakened skeletal support.

Mission Launch Date	Mission Name	Mission Objectives	
1994 (6-month inflight study)	Rodent Bone Study	1. Metabolic Balance 3. Postflight Recovery	2. Bone Loss 4. Countermeasures
1996 (9-month inflight study)	Primate Bone Study	1. Soft Tissue Changes 3. Postflight Recovery	2. Bone Loss 4. Countermeasures
1999 (6-9 month inflight study)	Human Bone Study	1. Soft Tissue Changes 3. Postflight Recovery	2. Bone Loss 4. Countermeasures

Mission Scenario Justification

The dynamic events related to calcium and phosphorous metabolism and regulation in humans during long-term space flight are not well understood. The early, calcium related, missions are designed to improve our understanding of the nature of the skeletal events themselves, and to assess the degree of skeletal degradation and its impact upon man's long-term performance in space and reentry to Earth. The rodent mission will provide histological data that is very difficult to obtain in primates and man. The primate mission validates and extends the rodent data to include soft tissue metabolic and hormonal regulatory data, and serves as the connecting link between the human non-invasive data and the rodent invasive data. The human mission establishes a baseline of normal calcium metabolism during space flight, confirms the results provided by the two animal models, and tests the validity of effective countermeasures appropriate to long-duration space flight.

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of The Effect of Space Flight
on Bone Metabolism

Category: Biomedical Problems/Musculoskeletal (Bone)

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Rodent Bone Study	1. <u>Metabolic Balance</u> . To perform a complete calcium metabolic balance study in order to indirectly assess the state of bone metabolism during long-duration space flight and to validate the use of the rodent as an appropriate model for the human in these circumstances.	1. Metabolic Balance a) Dietary monitoring b) Urine and fecal collection/analysis c) Plasma collection/analysis after animal sacrifice.	Rodent: male 80 Total Sacrifice schedule: 10 preflight 10/month for 6 months 10 one-month post-flight	Computer Tomograph Radiation Counter	All of these objectives require a man-tended laboratory facility with controlled atmosphere, temperature, and lighting. This facility should be capable of supporting: biochemical analyses of urine, plasma, and feces; appropriate histological studies; the use of radioactive materials; and should be capable of housing the required number of rodents.
	2. <u>Bone Loss</u> . To trace long-term progressive bone loss in the rodent through mainly invasive methods.	2. Bone Loss a) Computer tomograph examination b) Tracer studies c) Rodent sacrifice d) Histological examination			
	3. <u>Postflight Recovery</u> . To trace the recovery of the calcium/bone system of rodents exposed to long-duration space flight.	3. Postflight Recovery. a) Continuation of the above metabolic and bone studies in rodents returned from space flight.			
	4. <u>Countermeasures</u> . To evaluate specific countermeasures for long-duration bone loss in rodents during space flight.	4. Countermeasures* a) Supplemental dietary phosphorous b) Regulated exercise program *Metabolic balance and bone loss studies should be conducted using the rodents involved in the countermeasure study.	Rodent: male 20 Total Sacrifice schedule: all sacrificed on the last day inflight Treatment: 10 phosphorous 10 exercise		

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of The Effect of Space Flight
On Bone Metabolism

Category: Biomedical Problems/Musculoskeletal (Bone)

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Primate Bone Study	1. <u>Soft Tissue Changes.</u> To trace the dynamic events related to soft tissue metabolic and hormonal regulatory components of the calcium and phosphorous systems of the primate in order to validate the primate as an appropriate model for the human. In addition, this mission should validate and extend data previously gathered from the rodent studies.	1. Soft tissue changes Metabolic balance and hormonal monitoring including: a) Dietary monitoring b) Urine and fecal collection/analysis c) Plasma collection/analyses	Primate: male 8 Total (Typical) Sacrifice schedule: 4 last day inflight 4 one-month postflight	Computer Tomograph Radiation Counter	All of these objectives require a man-tended laboratory facility with controlled atmosphere, temperature, and lighting. This facility should be capable of supporting: biochemical analyses of urine; plasma; and feces; the use of radioactive materials; and should be capable of housing the required number of primates.
	2. <u>Bone Loss.</u> To trace long-term progressive bone loss in the primate through mainly non-invasive methods.	2. Bone Loss a) Computer tomograph examination b) Tracer studies c) Primate sacrifice d) Histological examination			
	3. <u>Postflight Recovery.</u> To trace the recovery of the calcium/bone system of primates exposed to long-duration space flight.	3. Postflight Recovery Continuation of the above metabolic and bone studies on primates returned from space flight.			
	4. <u>Countermeasures.</u> To evaluate specific countermeasures for long-duration bone loss in primates during space flight.	4. Countermeasures* a) Supplemental dietary phosphorous * Metabolic balance and bone loss studies should be conducted using the primates involved in the countermeasure study.	Primate: male 4 Total Sacrifice schedule: all last day inflight		

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of The Effect of Space Flight
On Bone Metabolism

Category: Biomedical Problems/Musculoskeletal

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Human Bone Study	1. <u>Soft Tissue Changes</u> . To trace the soft tissue metabolic and regulatory components of the calcium and phosphorous systems of the human in order to confirm the validation of the rodent and primate models and to establish a baseline of normal human calcium metabolism during space flight.	1. Soft tissue changes. Metabolic balance and hormonal monitoring including: a) Dietary monitoring b) Urine and fecal collection/analyses c) Plasma collection/analyses d) Intestinal absorption study	Human 6 Total (Typical)	Computer Tomograph	All of these objectives require a man-tended laboratory facility with controlled atmosphere, temperature, and lighting. This facility should be capable of supporting biochemical analyses of urine, plasma, and feces, and the use of radioactive materials.
	2. <u>Bone Loss</u> . To trace long-term progressive bone loss in the human through non-invasive methods.	2. Bone Loss a) Computer tomographic examination			
	3. <u>Postflight Recovery</u> . To trace the recovery of the calcium/bone system of humans exposed to long-duration space flight and to validate and confirm similar data collected from rodents and primates.	3. Postflight Recovery. Continuation of the above metabolic and bone studies on humans returned from space flight.			
	4. <u>Countermeasures</u> . To evaluate specific countermeasures for long-duration bone loss in humans if it is found (through previous rodent and primate studies) that such countermeasures are both required and potentially beneficial.	4. Countermeasures* a) Supplemental dietary phosphorous b) Monitored exercise program * Metabolic balance and bone loss studies should be conducted using the humans involved in the countermeasure study.	Human 6 Total 3 treated with phosphorous 3 treated with exercise	Exercise Facilities	

LIFE SCIENCES
ISSUE SUMMARY SHEET
BIOMEDICAL PROBLEMS

DISCIPLINE

ISSUE

MUSCULOSKELETAL (MUSCLE)

Assessment of suitable countermeasures with which to protect the muscular integrity of man during long-duration space flight, including an investigation of the following questions:

- (1) What is the nature of muscle atrophy during space flight?
- (2) How does muscle atrophy compare in postural and nonpostural muscles?
- (3) Is the muscle atrophy reversible after return to Earth?
- (4) What amounts of dietary protein and energy are required to sustain muscle integrity and protein metabolism during space flight?

LIFE SCIENCES
INTEGRATED MISSION SCENARIO

Issue: Assessment of The Effect of Space Flight on Muscle Metabolism
Category: Biomedical Problems/Musculoskeletal (Muscle)

Background

Increases in the urine excretion rates of amino acids, decreases in lean body mass and muscle strength, and changes in electromyographic responses during the Skylab missions suggest that skeletal muscle mass and strength is reduced during space flight. The atrophy is assumed to occur mainly in postural muscles and is due to a lack of conditioning, simply through disuse. Most of the changes in muscle-related measurements, except the excretion rates of the amino acids, were reversible with a proper exercise program. This suggests, then, that either muscle atrophy is occurring in other muscles, not previously measured (such as the back and stomach), or that the amino acid excretion rates are related to factors other than muscle degradation (such as diet). Of concern is whether the exercise program used in Skylab 3 is sufficient protection against, and whether complicating factors, such as dietary intake of protein and energy, are actively involved in muscle atrophy during longer-term (6-9 months) space flights.

MISSION LAUNCH DATE	MISSION NAME	MISSION OBJECTIVES	
1994 (6-month inflight study)	Rodent Muscle Study	1. Muscle Histology 3. Postflight Recovery	2. Metabolic Balance 4. Countermeasures
1995 (6-9 month inflight study)	Primate Muscle Study	1. Muscle Histology 3. Postflight Recovery	2. Protein Metabolism 4. Countermeasures
1997 (6-9 month inflight study)	Human Muscle Study	1. Muscle Metabolism 3. Postflight Recovery	2. Protein Metabolism 4. Countermeasures

Mission Scenario Justification

Reliable countermeasures are required to protect man from muscle atrophy and protein loss during long-duration space flight. The two most important preventative agents are diet and exercise, but the optimum countermeasure has not been established. The rodent mission will provide data on the nature of the tissue and cellular changes and how they relate to the protein metabolic changes. Such data are difficult to obtain in the primate and human. The primate mission will extend the rodent protein studies and test some of the better rodent countermeasures in a larger, upright animal. The human mission should confirm the results provided by the two animal studies, and should test the effectiveness of the countermeasures established for the long-duration space flight.

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of The Effect of Space Flight
On Muscle Metabolism

Category: Biomedical Problems/Musculoskeletal

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Rodent Muscle Study	1. <u>Muscle Histology</u> . To trace the long-term progressive changes in muscle cells and tissues in order to assess the biochemical, histological, and electromyographic nature of muscle atrophy during space flight.	1. Muscle Histology a) Electromyography b) Sacrifice c) Muscle strength and size d) Histological examination e) Biochemical examination f) Tracer studies	Rodent: Male 110 Total Sacrifice Schedule: 10 preflight 10/month for 6 months	Electromyograph Radiation Counter	All of these objectives require a man-tended laboratory facility with controlled atmosphere, temperature, and lighting. This facility should be capable of supporting: biochemical analyses of urine, feces, and plasma; appropriate histological studies; the use of radioactive studies; and should be capable of housing the required number of rodents.
	2. <u>Metabolic Balance</u> . To perform a complete metabolic balance of particular amino-acids to indirectly assess protein metabolism.	2. Metabolic Balance a) Dietary monitoring b) Urine and fecal collection/analysis c) Plasma collection/analysis after sacrifice d) Tracer studies	10/week for 1 month postflight		
	3. <u>Postflight Recovery</u> . To trace the recovery of the muscle loss of rodents exposed to long-duration space flight.	3. Postflight Recovery Continuation of the above metabolic protein and histological muscle studies from rodents returned from space flight.			
	4. <u>Countermeasures</u> . To evaluate specific countermeasures for long-duration muscle loss in rodents during space flight.	4. Countermeasures* a) Dietary manipulation b) Regulated exercise program * Muscle histology and metabolic balance should be conducted on rodents involved in countermeasure study.	Rodent: Male 70 Total Treatment 10 Diet 1 10 Diet 2 10 Diet 3 10 Exercise Program 1 10 Exercise Program 2 10 Exercise Program 3 10 Diet Program & Exer. Sacrifice schedule: All last day inflight	Exercise Facilities for Rodents	

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of The Effect of Space Flight
On Muscle Metabolism

Category: Biomedical Problems/Musculoskeletal (Muscle)

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Primate Muscle Study	1. <u>Muscle Histology</u> . To trace the long-term progressive loss of muscle cells and tissues in primates during space flight, and to compare primate histological data to the rodent histological data.	1. Muscle Histology a) Electromyography b) Sacrifice c) Muscle strength and size d) Histological examination e) Biochemical examination f) Tracer studies	Primate: Male 8 Total Sacrifice Schedule: 4 last day inflight 4 one-month post-flight	Electromyograph Radiation Counter	All of these objectives require a man-tended laboratory facility with controlled atmosphere, temperature, and lighting. This facility should be capable of supporting biochemical analyses of urine, feces, and plasma; appropriate histological studies; the use of radioactive studies; and should be capable of housing the required number of primates.
	2. <u>Protein Metabolism</u> . To trace the dynamic long-term changes in protein metabolism during space flight and to validate the primate as an appropriate human model. In addition, this mission should validate and extend data previously gathered from the rodent studies.	2. Protein Metabolism a) Metabolic balances of specific amino acids b) Tracer studies			
	3. <u>Postflight Recovery</u> . To trace the recovery of the muscle loss and the protein metabolic changes of primates exposed to long-duration space flight.	3. Postflight Recovery. Continuation of the above histological and metabolic studies on primates returned from space flight.			
	4. <u>Countermeasures</u> . To evaluate specific countermeasures for long-duration muscle atrophy in primates during space flight.	4. Countermeasures* a) Dietary manipulation b) Regulated exercise program * Muscle histology and metabolic balance should be conducted on primates involved in countermeasure study.	Primates: Male 30 Total Treatment 6 Diet 1 6 Diet 2 6 Exercise Program 1 6 Exercise Program 2 6 Diet + Exercise X Sacrifice Schedule: 1/2 of each group last day inflight	Primate Exercise Facilities	

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of The Effect of Space Flight
On Muscle Metabolism

Category: Biomedical Problems/Musculoskeletal (Muscle)

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Human Muscle Study	1. <u>Muscle Metabolism</u> . To assess the effectiveness of specific countermeasures on muscle mass, biochemistry, histology, and electromyography during long-duration space flight. In addition, this mission should test and validate the countermeasure studies of the rodent and primate missions.	1. Muscle Metabolism a) Biosteriometric analysis b) Nitrogen, lean body mass, and potassium analyses c) Biochemical examination on tissue sample d) Histological examination on tissue sample e) Electromyography f) Muscle strength	Human 10 Total Treatment 5 Diet 1 + Exercise 1. 5 Diet 2 + Exercise 2.	Human Exercise Facilities Biosteriometry Equipment Radiation Counter	All of these objectives require a man-tended laboratory facility with controlled atmosphere, temperature, and lighting. This facility should be capable of supporting: biochemical analyses of urine, feces, and plasma; appropriate histological studies; and the use of radioactive studies.
	2. <u>Protein Metabolism</u> . To trace the changes in protein metabolism, in humans under treatment with specific countermeasures, during long-duration space flight.	2. Protein Metabolism a) Metabolic balances b) Tracer studies			
	3. <u>Postflight Recovery</u> . To assess the effectiveness of the countermeasures through the degree of performance deficiency, muscular atrophy, and protein metabolic degradation; and to trace their recovery upon return to Earth.	3. Postflight Recovery Continuation of the above muscle and protein studies on humans returned from space.			
	4. <u>Countermeasures</u> . To evaluate the effectiveness of particular countermeasures in reducing or eliminating muscle atrophy during long-duration space flight.	4. Countermeasures			

LIFE SCIENCES
ISSUE SUMMARY SHEET
BIOMEDICAL PROBLEMS

DISCIPLINE

ISSUE

HEMATOLOGICAL

Assessment of the effect of space flight on the humoral and cellular regulation of erythropoiesis, including an investigation of the following questions:

- (1) What is the nature of the effect of space flight on erythropoiesis regulation?
- (2) What are the exact mechanisms involved in the observed decreases in circulating red mass?
- (3) Does the stress of space flight alter the ability of the system to respond to erythroid stresses?
- (4) Are the effects of long-term space flight completely reversible upon return to Earth?

LIFE SCIENCES
INTEGRATED MISSION SCENARIO

Issue: Assessment of the Effect of Space Flight on the
Humoral and Cellular Regulation of Erythropoiesis

Category: Biomedical Problems/Hematological

Background

The most consistent finding relative to the influence of space flight on the hematologic system in man has been a significant reduction in the circulating red cell mass. Different mechanisms have been proposed for this decrease in blood volume. Studies with animals have been interpreted as indicating increased random hemolysis. The most recent data from human experiments support the concept that a suppression of erythropoiesis during flight is the major factor in this change. Some of these factors will be examined in future Shuttle Spacelab missions including the first life sciences dedicated Spacelab mission, SL-4. However, the exact etiology of this observed decrease in red cell mass is unknown, and the restrictions such a decrease might place on longer missions remain a matter of conjecture.

MISSION LAUNCH DATE	MISSION NAME	MISSION OBJECTIVES	
1995 (4-month inflight study)	Rodent Blood Study	1. Metabolic Balance 3. Erythroid Stress	2. Red Cell Mass Loss 4. Postflight Recovery
1997 (6-month inflight study)	Primate Blood Study	1. Metabolic Balance 3. Erythroid Stress	2. Red Cell Mass Loss 4. Postflight Recovery
1998 (6-month inflight study)	Human Blood Study	1. Metabolic Balance 3. Postflight Recovery	2. Red Cell Mass Loss

Mission Scenario Justification

The dynamic events related to the observed decrease in red cell mass occurring during space flight are not well understood. The early missions are designed to improve the understanding of the nature of the changes that take place in the erythropoietic system and to assess the degree and time course of these changes during long-term space flight and recovery on Earth. The rodent and primate missions allow one to manipulate the system and to collect histological data that are difficult to obtain in humans. The human mission will not only establish a baseline of normal erythropoiesis regulation during space flight and confirm the results provided by the two animal models; it will also provide the information necessary to clarify the questions that have been raised during previous manned space flight: does the decrease in red cell mass represent an adaptation to a new zero-g related steady state, or is the decrease part of a transient response to the stress of space flight in which red cell mass will slowly return, during long-duration space flight, to its preflight value? The results from these experiments should also help to define the exact mechanisms involved in the decrease of red cell mass, regardless of whether the cause of the decrease is due to a reduction in red blood cell production caused by hemoconcentration, nutrition, decreased erythropoietin response, or other factors, or whether this decrease is due to an increase in destruction caused by hemolysis, decreased red-cell half life, or membrane fragility.

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of The Effect of Space Flight on the
Humoral and Cellular Regulation of Erythropoiesis

Category: Biomedical Problems/Hematological

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Rodent Blood Study	1. <u>Metabolic Balance</u> . To obtain a complete dietary and fluid record in order to assess the role that nutritional status plays in erythropoiesis control in rodents.	1. Metabolic Balance a) Dietary monitoring b) Urine volume c) Body mass measurements	Rodent: Male 114 Total Sacrifice Schedule: 6 preflight 6/week for first four weeks inflight 12/month for months 2, 3, and 4 inflight 6/week first four weeks postflight 12/month for month 2 postflight	Radiation counter Rodent hypoxic test chambers	All of these objectives require a man-tended laboratory facility with controlled atmosphere, temperature, and lighting. This facility should be capable of supporting biochemical analyses of plasma and serum, the use of radioactive materials, and should be capable of housing the required number of rodents.
	2. <u>Red Cell Mass Loss</u> . To document the time course of change in the erythropoietic system in rodents exposed to long-term space flight, and to help elucidate the mechanisms involved. In addition, this mission should validate the use of rodents as an appropriate model for the human.	2. Red Cell Mass Loss. Analysis of erythropoietic system. a) Blood analysis. Hematological indices and measurements b) Tracer studies c) Hormonal studies d) Rodent sacrifice and histological examination			
	3. <u>Erythroid Stress</u> . To evaluate the ability of the rodent system to respond to erythroid stresses during exposure to long-term space flight.	3. Erythroid Stress. Analysis of stress response. a) Hormonal studies b) Blood analysis c) Rodent sacrifice and histological examination			
	4. <u>Postflight Recovery</u> . To trace the recovery of the erythropoietic system in rodents exposed to long-duration space flight.	4. Postflight Recovery Continuation of the above metabolic, red cell mass, and erythroid stress studies in rodents returned from space flight.			

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of The Effect of Space Flight on the
Humoral and Cellular Regulation of Erythropoiesis

Category: Biomedical Problems/Hematological

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Primate Blood Study	1. <u>Metabolic Balance</u> . To obtain complete dietary and fluid records in order to assess the role of nutritional status in erythropoiesis control in primates.	1. Metabolic Balance a) Dietary monitoring b) Urine volume c) Body mass measurements	Primates: Male 12 Total 6 inflight controls 6 inflight hypoxic stress	Radiation Counter Primate Hypoxic Test Chambers	All of these objectives require a man-tended laboratory facility with controlled atmosphere, temperature, and lighting. This facility should be capable of supporting biochemical analyses of plasma and serum, the use of radioactive materials, and should be capable of housing the required number of primates.
	2. <u>Red Cell Mass Loss</u> . To document the time course of change in the erythropoietic system in primates exposed to long-term space flight, and to help elucidate the mechanism involved. In addition, this mission should validate the use of the primate as an appropriate model for the human, and provide the link connecting rodent and human studies.	1. Red Cell Mass Loss. Analysis of erythropoietic system. a) Blood analysis b) Tracer studies c) Hormonal studies			
	3. <u>Erythroid Stress</u> . To evaluate the ability of the primate system to respond to erythroid stresses during exposure to long-term space flight.	3. Erythroid Stress. Analysis of stress response a) Blood analysis b) Hormonal studies			
	4. <u>Postflight Recovery</u> . To trace the recovery of the erythropoietic system in primates exposed to long-duration space flight.	4. Postflight Recovery Continuation of the metabolic balance, red cell mass, and erythroid stress studies in primates returned from space flight			

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of The Effect of Space Flight on the
Humoral and Cellular Regulation of Erythropoiesis

Category: Biomedical Problems/Hematological

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Human Blood Study	1. Metabolic Balance. To obtain dietary and fluid records in order to assess the role of nutritional status in erythropoiesis control in humans.	1. Metabolic Balance a) Dietary monitoring b) Urine volume c) Body mass measurement	Human 6 total	Radiation Counter	All of these objectives require a man-tended laboratory with controlled atmosphere, temperature, and lighting. This facility should be capable of supporting biochemical analyses of plasma and serum as well as the use of radioactive materials.
	2. Red Cell Mass Loss. To document the time course of change in the erythropoietic system in humans exposed to long-term space flight, and to help elucidate the mechanism involved. In addition, this mission should confirm the validation of the rodent and primate models and to establish a baseline of normal human erythropoiesis during space flight.	2. Red Cell Mass Loss. Analysis of erythropoietic system a) Blood analysis b) Tracer studies c) Hormonal studies			
	3. Postflight Recovery. To trace the recovery of the human erythropoietic system exposed to long-duration space flight and to confirm similar data collected from rodents and primates.	3. Postflight Recovery Continuation of the metabolic and red cell mass loss studies on humans returned from space flight.			

LIFE SCIENCES
ISSUE SUMMARY SHEET
BIOMEDICAL PROBLEMS

DISCIPLINE	ISSUE
CARDIOVASCULAR	<p>Assessment of the effect of space flight on cardiovascular adaptation, including an investigation of the following questions:</p> <ol style="list-style-type: none"><li data-bbox="968 699 1692 756">(1) What functional and structural changes lead to cardiovascular deconditioning?<li data-bbox="968 776 1692 833">(2) Are long-term adaptive cardiovascular changes reversible? If not, what are the consequences?<li data-bbox="968 852 1650 909">(3) Are untrained subjects more susceptible to cardiovascular dysfunction than trained astronauts?<li data-bbox="968 928 1629 985">(4) What inflight countermeasures are effective in reducing orthostatic intolerance during reentry and postflight?

LIFE SCIENCES
INTEGRATED MISSION SCENARIO

Issue: Cardiovascular Deconditioning and Adaptation During Space Flight
Category: Biomedical Problems/Cardiovascular

Background

No major impairment of cardiovascular function has been observed to date in space flights ranging in duration up to 6 months. However, functional cardiovascular abnormalities manifested as orthostatic intolerance and reduced exercise capacity have consistently been demonstrated in astronauts during immediate postflight period. These manifestations, coupled with the fact that exercise capacity is maintained in space, suggest that the postflight cardiovascular dysfunction is the result of an appropriate adaptation to altered fluid distribution in zero-g, suddenly rendered inappropriate upon return to the 1-g environment. Although some factors involved in the adaptation process (blood volume loss, for example) have been identified, the underlying mechanisms are far from clear at the present time. A more pressing problem from an operational standpoint is the development of suitable countermeasures to offset the potentially debilitating effects of cardiovascular deconditioning in zero-g. The long-term space station studies will provide an opportunity to fully address both these questions. It is assumed that the acute phase (7-10 days) of cardiovascular adaptation to weightlessness will be thoroughly studied during the Shuttle/Spacelab era, and that appropriate countermeasures related to short-term deconditioning (mainly fluid-electrolyte related) will be developed and available prior to the space station studies.

MISSION LAUNCH DATE	MISSION NAME	MISSION OBJECTIVES
1992 (6-month inflight study)	Human Cardiovascular Study	1. Cardiovascular Deconditioning 2. Countermeasures 3. Postflight Recovery
1995 (9-12 month inflight study)	Primate Cardiovascular Study	1. Cardiovascular Adaptation
1999 (6-month inflight study)	Dog Cardiovascular Study	1. Cardiovascular Regulation

Mission Scenario Justification

Since it is assumed that acute cardiovascular changes that occur immediately upon entry into space will have been fully examined during the Shuttle-Spacelab missions, the main elements of the proposed space-station studies relate to long-term cardiovascular adaptation. The time-course of adaptive changes will be followed in humans, primates, and dogs through measurement of a large number of cardiovascular variables throughout the mission. In humans, the measurements will be made noninvasively both at rest and during provocative stress testing. In primates, the measurements will be continued in an extended-duration mission in order to help identify the factors that might cause irreversible cardiovascular changes with prolonged exposure to zero-g. In dogs, the measurements will include functional and structural changes of the cardiovascular system under weightless conditions. Taken together, the studies are aimed at providing a comprehensive knowledge of the mechanisms of cardiovascular adaptation in zero-g. In addition to examining adaptive changes, the human studies are directed at testing the effectiveness of countermeasures in combating long-term cardiovascular deconditioning in zero-g. A large number of possible countermeasures exist and even more are likely to be suggested during the coming era of frequent flights. As an example of a countermeasure study, a combination of saline ingestion and LBNP application is proposed, but it is suggested that the most appropriate countermeasure should be determined only after more data have been collected from the next decade of Shuttle flights.

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Cardiovascular Deconditioning and Adaptation During Space Flight

Category: Biomedical Problems/Cardiovascular

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Human Cardiovascular Study	<p>1. <u>Cardiovascular Deconditioning.</u> To trace the time course of development of cardiovascular deconditioning through monitoring of cardiovascular indices, both at rest, and during provocative stress tests.</p>	<p>1. Cardiovascular Deconditioning</p> <p>a) Measurements and procedures include:</p> <p>ECG/Heart rate Indirect blood pressure Cardiac output Echocardiography Leg volume Plasma volume Red cell mass Regional blood flow (renal and cerebral) Indirect retinal pressure Retinal photography Ocular tonometry</p> <p>b) LBNP test</p> <p>c) Baroreflex test</p> <p>d) Pharmacological interventions</p>	<p>Human</p> <p>8 Total</p> <p>4 control</p> <p>4 countermeasures</p>	<p>Gamma Camera</p> <p>Ocular Tonometer</p> <p>LBNP Device</p> <p>Baroreflex Test Equipment</p>	<p>A man-tended cardio-pulmonary laboratory with controlled atmosphere and lighting, and facilities for analyses and handling of blood samples and radioactive substances.</p>

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Cardiovascular Deconditioning and Adaptation During Space Flight (Continued)

Category: Biomedical Problems/Cardiovascular

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Human Cardiovascular Study	2. <u>Countermeasures</u> . To test the effectiveness of inflight countermeasures in reducing cardiovascular deconditioning.	2. Countermeasures Utilize the above measurements to compare the responses with and without countermeasures. The countermeasure will consist of saline ingestion coupled with LBNP application administered several times during flight.			
	3. <u>Postflight Recovery</u> . To determine the degree of orthostatic intolerance with and without countermeasures.	3. Postflight Recovery a) Tilt studies b) Exercise studies c) Measurements for several weeks postflight d) Measurements of ECG/heart rate, indirect arterial and retinal blood pressures during reentry.			

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Cardiovascular Deconditioning and Adaptation During Space Flight

Category: Biomedical Problems/Cardiovascular

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Primate Cardiovascular Study	1. <u>Cardiovascular Adaptation.</u> To determine if cardiovascular changes due to long-term space flight are reversible.	1. Cardiovascular Adaptation a) Monitoring of basic cardiovascular variables (ECG/heart rate, arterial and central venous blood pressures) from several weeks preflight to several weeks postflight with chronically implanted electrodes and catheters. b) Monitoring of body weight and food and water consumption c) Postflight morphological and histological examinations of cardiac tissue and tissues of major blood vessels.	Primate 4 control group(ground) 4 flight group Sacrifice Schedule 2 from each group one month after flight 2 from each group two months after flight	Telemetered monitoring equipment	A man-tended primate facility.

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Cardiovascular Deconditioning and Adaptation During Space Flight

Category: Biomedical Problems/Cardiovascular

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Dog Cardiovascular Study	1. <u>Cardiovascular Regulation.</u> To determine micro- and macrocirculatory and cardiac changes elicited by hypogravic stress.	1. Cardiovascular Regulation a) Microcirculatory studies with skin-flap prior to sacrifice b) Acute studies with measurements of ECG/heart rate Aortic flow Left ventricular pressure Carotid artery pressure Femoral artery pressure Right atrial pressure c) Response to pharmacological agents d) Response to electrical stimulation of vagus and sympathetic efferents e) Morphological and histological examinations of the heart and major arteries and veins f) Monitoring of body weight, and food and water consumption	Dog 16 Total Sacrifice Schedule 4 preflight (control) 4 inflight after 3 months 4 inflight after 6 months 4 postflight	Electron microscope Electrical stimulator Flowmeter Pressure transducers Equipment for microcirculatory studies	A man-tended laboratory facility with controlled atmosphere and lighting to house 12 dogs and equipped with surgical supplies for performing animal experiments. It should be capable of supporting microscopic studies and biochemical analyses of plasma.

LIFE SCIENCES
ISSUE SUMMARY SHEET

BIOMEDICAL PROBLEMS

DISCIPLINE	ISSUE
RENAL-ENDOCRINE/ FLUID-ELECTROLYTE	<p>Assessment of the homeostatic mechanisms responsible for maintaining fluid and salt balance in weightlessness, including an investigation of the following questions:</p> <ol style="list-style-type: none">(1) What long-term adaptive changes occur in renal function?(2) Do the renal-regulating hormones exhibit a characteristic response during long-term exposure to weightlessness as they appear to show for acute entry into zero-g?(3) What are the factors that control these hormones and what role do they play in maintaining water and salt homeostasis during chronic periods of weightlessness?(4) Is there an alteration in evaporative water loss in zero-g and can this be responsible for changes in observed renal excretion?(5) Is the renal response to fluid and salt loading altered as a result of long-term exposure to weightlessness?

LIFE SCIENCES
INTEGRATED MISSION SCENARIO

Issue: Assessment of the Effects of Space Flight on Fluid
and Salt Balance and Renal Function

Category: Biomedical Problems/Renal-Endocrine

Background

There is unequivocal evidence that weightlessness results in significant fluid redistribution within the body, including a shift of blood and tissue fluid from the lower body to the central circulation. As a result of central volume expansion a complex set of reactions occur, including participation of hemodynamic, autonomic, and hormone systems, which lead to a loss of extracellular fluid and electrolytes from the body. These acute processes will be intensively examined in the Shuttle Spacelab during the coming decade and will be interpreted in the light of a reasonably complete theoretical context. It will be presumed that the studies conducted on a space station can begin to focus on more long-term adaptive changes. Some of these chronic effects of weightlessness were observed during Skylab, but their etiology is elusive because of a lack of a general theoretical framework regarding adaptation. Previous findings which demand further investigation in a space station setting include: a) a reduction in plasma volume which does not seem to recover even in the face of water loading, b) hormone disturbances which are considered paradoxical regarding renal regulation, c) hyponatremic plasma which is maintained in spite of several regulatory factors acting to correct this condition, d) excess renal excretion of water and salts which have led several investigators to think that alarming body losses are occurring, and e) indirect evidence suggesting a decrease in sweat losses which has yet to be measured or explained. An understanding of these issues, in particular, and of fluid and salt balance during zero-g in general, is crucial because proper fluid-electrolyte regulation is at the heart of the maintenance of crew health in weightlessness and of the ability of astronauts to fully recover in one-g.

MISSION LAUNCH DATE	MISSION NAME	MISSION OBJECTIVES	
1995 (2-3 month inflight study)	Primate Renal-Endocrine Study	1. Approach to Adaptation 3. Histology	2. Response to Dietary Disturbances 4. Postflight Recovery
1992 (4-month inflight study)	Human Renal-Endocrine Study	1. Renal-Endocrine Adapta- tion to Zero-g 3. Effects of Evaporative Water Loss on Renal Function	2. Renal-Function Tests 4. Readaptation to 1-g

Mission Scenario Justification

(Continued following page)

LIFE SCIENCES
INTEGRATED MISSION SCENARIO
(Continued)

Mission Scenario Justification

Although losses of extracellular fluids and salts (including plasma volume) appear to stabilize in space flight after several days (assuming normal dietary intake), there are indications that equilibrium of the entire fluid-electrolyte system does not occur until after months of adaptation. These slower acting processes are not well understood and it is the purpose of the proposed studies to characterize and possibly explain their etiology. Parallel studies in the human and primate will help define the utility of the primate as an appropriate human surrogate for long-term studies. These will complement the 7-10 day studies in the primates scheduled for Shuttle Spacelab and the longer-term Skylab studies in human subjects. A study of renal-endocrine adaptation is designed to characterize the new homeostatic levels after a month or so of space flight, and then to alter these levels by a simple dietary change. It is proposed to increase the levels of sodium and decrease the levels of potassium in the diet so as to change the direction of the plasma electrolytes from the hyponatremic and hyperkalemic states expected on the basis of Skylab results. This portion of the experiment is designed to determine whether the renal-regulating hormones (i.e., aldosterone, angiotensin, ADH, prostaglandins, natriuretic factor) are under the chronic influence of the plasma electrolytes or of the circulatory pressures. Supplementary studies in the primate are proposed to examine the consequences of zero-g adaptation and dietary alterations on fluid compartment volumes, renal plasma flows, and histology of hormone secreting and target organs (including stress related hormones). The use of stress tests are recognized in biomedicine as a means of eliciting more meaningful information about the state of an organ system than merely observing the system at rest. A human experiment is included involving several renal function tests (water and salt loading) which should provide much useful information regarding the water and salt handling capability of the body. Skylab results demonstrated an increase in urinary fluid and electrolyte losses which could imply that body water and sodium losses continue unabated during months of weightlessness. However, there is reasonable (but indirect) evidence to suggest that renal losses were excessive, in part, because of diminished sweat and evaporative water loss. That is, a decrease in sweat losses will have a renal effect similar to that which occurs when dietary intake increases. Direct measurements of sweat losses, as proposed here, would resolve this issue.

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of the Effect of Space Flight on Fluid and Salt Balance
and Renal Function

Category: Biomedical Problems/Renal-Endocrine

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Primate Renal-Endocrine Study	1. Approach to Adaptation. To characterize the adaptive changes which lead to a new homeostatic level appropriate to zero-g for the fluid, electrolyte, endocrine, and renal systems. This mission will also validate the primate for long-term zero-g studies.	<p>1. Approach to Adaptation</p> <p>a) Study begins within one week after achieving weightlessness</p> <p>b) Metabolic balance, blood and urine sampling</p> <ul style="list-style-type: none"> - Controlled diet similar to that in 1-g - Daily monitoring of urine and fecal samples - Weekly monitoring of plasma samples - Analysis of plasma/urine for electrolytes and hormones <p>c) Fluid volumes and renal clearances</p> <ul style="list-style-type: none"> - Weekly measurement of blood volume, body water - Twice weekly measurement of body mass - Weekly monitoring of renal clearances <p>d) Circulatory pressures</p> <ul style="list-style-type: none"> - Daily monitoring of arterial, venous, and renal pressures 	<p>Primate: male</p> <p>N = 8</p> <p>Sacrifice Schedule:</p> <p>4 after 3 months inflight</p> <p>4 after one-month postflight</p>	<p>Plasma/urine analyzer</p> <p>Radiation counter</p>	<p>These objectives require a man-tended laboratory facility with controlled atmosphere, temperature, and lighting. This facility should be capable of supporting biochemical analyses of urine, plasma, and feces, the use of radioactive materials, and should be capable of housing the required number of primates. Surgical facilities should be available to perform catheterizations and animal sacrifice.</p>

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of the Effect of Space Flight on Fluid and Salt Balance
and Renal Function

Category: Biomedical Problems/Renal-Endocrine

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Primate Renal-Endocrine Study	2. <u>Response to Dietary Disturbance.</u> To assess the mechanisms and pathways operative during metabolic stress in zero-g. To determine whether renal-regulating hormones are under the long-term influence of metabolic, rather than, circulatory factors. This study will also assess the consequences of electrolyte shifts on the redistribution of fluids and their composition.	2. Response to Dietary Disturbance a) Continuation of the above measurements, but with two types of dietary changes: i. sodium loading (daily allotment = 2x normal) ii. potassium restriction (daily allotment = 1/10 normal) b) Previous study and similar preflight study acts as control for this experiment.	As Above	As Above	
	3. <u>Histology.</u> To assess the morphological and histological changes that occur in renal tissue and stress-related organs after long-term exposure to zero-g.	3. Histology a) Primate sacrifice and tissue collection for postflight analysis.			
	4. <u>Postflight Recovery.</u> To characterize the postflight adaptation of the renal-endocrine systems. To trace the recovery of body fluids, their electrolyte composition, and hormone levels.	4. Postflight Recovery a) Continuation of the above metabolic, fluids renal, and circulatory studies on primates returned from space flight. b) Sacrifice primates after one-month recovery.			

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of The Effects of Space Flight
on Fluid and Salt Balance and Renal Function

Category: Biomedical Problems/Renal-Endocrine

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Human Renal-Endocrine Study	1. Renal-Endocrine Adaptation to Zero-g. To characterize homeostatic levels during prolonged weightlessness. To assess mechanisms and pathways operative during metabolic stress. To determine dietary effects on renal-endocrine system.	1. Renal-Endocrine Adaptation to Zero-g. a) Study begins after one month in zero-g. b) Normal controlled diet for 7 days c) Special diets for 7 days - high sodium diet - low potassium diet d) Measure plasma/urine electrolytes and hormones	Human 4 male 4 female	Plasma/urine analyzer	All of these objectives require a man-tended laboratory facility with controlled atmosphere, temperature, and lighting. This facility should be capable of supporting biochemical analyses of urine, plasma, and feces, and the use of radioactive materials. Body and sample mass measuring devices and standard cardiovascular assessment instrumentation are required.
	2. Renal-Function Tests. To assess changes in the ability of the kidneys to respond to acute and chronic fluid and electrolyte loads.	2. Renal-Function Tests a) Study to take place during 1st, 4th, 8th, and 16th weeks of space flight. b) Three renal stresses applied: i. fluid loading (1.5 liters in 5 min.) ii. salt loading (300 meq NaCl in 5 min.) iii. water deprivation ($\frac{1}{2}$ normal intake for 24 hours) c) Monitor urine volume, electrolytes, hormones, and creatine in plasma and urine.			

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of The Effects of Space Flight
on Fluid and Salt Balance and Renal Function

Category: Biomedical Problems/Renal-Endocrine

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Human Renal-Endocrine Study (Cont'd)	3. <u>Effects of Evaporative Water Loss on Renal Function.</u> To determine whether evaporative losses of water and salts decrease in space flight as predicted and to assess whether this can result in excess renal excretion.	3. Effects of Evaporative Water Loss on Renal Function. a) Study begins after two weeks in zero-g b) Controlled normal diet for 7 days, including controlled fluid intake c) Measure evaporative water loss and electrolyte composition of sweat during exercise d) Measure renal-losses of fluids and electrolytes e) Use 1-g control group	As Above	As Above	
	4. Readaptation to One-g. To repeat dietary adaptation and renal-function test studies (above) during the first month of recovery to assess the degree and speed of readaptation.	4. Readaptation to One-g a) Continuation of mission objectives 1 and 2.			

LIFE SCIENCES
ISSUE SUMMARY SHEET
BIOMEDICAL PROBLEMS

DISCIPLINE

ISSUE

VESTIBULAR

Determination of the effect of space flight on vestibular structure and function, including an investigation of the following questions:

- (1) What are the acute and adaptive effects of long-term space flight on the vestibular system's structure and function?
- (2) What are the mechanisms involved in space sickness and space flight vestibular dysfunction in general?
- (3) What is the time course of readaptation of the vestibular system to normal gravity following long-term space flight and how does this occur?

LIFE SCIENCES
INTEGRATED MISSION SCENARIO

Issue: Assessment of the Effect of Space Flight
on Vestibular Structure and Function

Category Biomedical Problems/Vestibular

Background

Manned space flight has revealed disturbances in the human vestibular system which manifest themselves through space sickness and disorientation. Symptoms of vestibular dysfunction have been reported by approximately 30 percent of the Apollo astronauts and 56 percent of the Skylab crewmembers. The symptoms remain for three to five days in space. This period appears to be followed by resistance to symptom reoccurrence for the remainder of the inflight phase. However, during the postflight phase symptomatology has been noted to reappear. Two possible causes for these events are a sensory conflict between vestibular, visual, and kinesthetic information and/or an inflight change in the vestibular physiology. In presenting this mission profile, it is assumed that the Shuttle-Spacelab flights prior to the realization of the Space Station will provide a comprehensive assessment of human vestibular function changes associated with space flight. It is also assumed that significant progress will be made in the development of countermeasures for space sickness, but that the etiology will not be well understood. This mission scenario is designed to determine the mechanisms involved and, therefore, allow the eventual refinement/enhancement of human countermeasures.

MISSION LAUNCH DATE	MISSION NAME	MISSION OBJECTIVES
1994 (4-month inflight study)	Rodent Physiologic Study	1. Vestibular Morphological Assessment 2. Vestibular Neurophysiological Assessment 3. Postflight Recovery
1996 (6-month inflight study)	Vestibular Function Study - Nonmammalian Vertebrates	1. Vestibular Function - Normal Response 2. Vestibular Function - Provocative Response 3. Postflight Recovery/Analyses
1999 (6-month inflight study)	Vestibular Function Study - Mammalian Vertebrates	1. Vestibular Function - Normal Response 2. Vestibular Function - Provocative Response 3. Postflight Recovery/Analyses

Mission Scenario Justification

The mechanisms responsible for vestibular dysfunction associated with space flight are not understood. The early rodent physiologic mission should provide data as to whether or not vestibular physiologic changes are involved, such as demineralization of the otoconia, and should determine the threshold and time course of these changes under various G levels. The nonmammalian and mammalian vestibular-function missions will serve to focus the assessment of this issue, based on the results of the early rodent mission, by providing data relevant to the sensory conflict theory and by furnishing information concerning the response of the vestibular system at various G levels in the initial, adaptive, and readaptive phases. By studying a variety of specimens it will be possible to observe the findings from lower through higher order animals. Results of these studies should allow eventual understanding of the human mechanisms involved with the subsequent refinement/enhancement of countermeasures and the development of better predictive indices.

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of the Effect of Space Flight
on Vestibular Structure and Function

Category: Biomedical Problems/Vestibular

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Rodent Vestibular Physiology Study	1. <u>Vestibular Morphological Assessment.</u> To study possible initial and adaptive morphological changes associated with the structure and ultrastructure of the vestibular system at various G levels in order to elucidate the mechanisms of vestibular dysfunction in 0-G while characterizing the graded response to micro gravity.	1. Vestibular Morphological Assessment. Morphological study of: a) Otoconia b) Utricle c) Sacculae d) Semicircular canals e) Neuroepithelium f) Cochlea	Rat: male 126 Total Usage: 6 preflight sacrifice 0-G Group 6/month for 4 months sacrificed inflight, 6 returned alive. 1-G Group 6/month for 4 months sacrificed inflight, 6 returned alive. 5-G Group 6/month for 4 months sacrificed inflight, 6 returned alive. 1.0-G group (control) 6/month for 4 months sacrificed inflight, 6 returned alive.	Scanning Electron Microscope Transmission Electron Microscope Microelectrodes w/ associated hardware	These objectives will necessitate a man-tended laboratory with the capability of supporting extensive morphological and neurophysiological studies, including surgery, and tissue analyses. Animal centrifuges with controlled atmosphere, temperature, lighting, and waste collection will also be required.
	2. <u>Vestibular Neurophysiologic Assessment.</u> To determine the initial neural response as well as any compensatory changes resulting from long-term exposure. Observe the behavioral repertoire to allow correlation with any morphological/neurophysiological changes.	2. Vestibular Neurophysiologic Assessment a) Electrode studies of neural activity utilizing normal/provocative stimuli. b) Video recording of animal movement and body position. c) Monitor food, water consumption and body weight.			
	3. <u>Postflight Recovery.</u> To determine the readaptive vestibular physiologic changes over time.	3. Postflight Recovery Physiologic assessment over a 2-3 month period postflight including the above parameters.	Utilize the inflight animals returned alive.	Vestibular Research Facility (on Earth)	

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of the Effect of Space Flight
on Vestibular Structure and Function

Category: Biomedical Problems/Vestibular

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Vestibular Function Study-Nonmammalian Vertebrates	1. <u>Vestibular Function-Normal Response.</u> To determine the initial changes in vestibular function as well as the compensatory changes resulting from long-term exposure in a number of nonmammalian vertebrates at various G levels in order to characterize the zero-g response as well as the graded response to microgravity.	1. Vestibular Function - Normal Response a) Electrode studies of afferent neural activity. b) Postural reflex, ocular counterrolling recording/monitoring. c) Video recording of animal movement and body position. d) EEG e) Monitor food, water consumption and body weight. f) Video recording of fish orientation/looping response.	Pigeon - 20 Total 4 preflight 16 Inflight - 4 each at: 0-g .1-G, .5-G, 1.0-G Frog - 20 Total 4 preflight 16 Inflight - 4 each at: 0-g .1-G, .5-G, 1.0-G Goldfish - 80 Total 16 preflight 64 Inflight - 16 each at: 0-g .1-G, .5-G, 1.0-G	Neurophysiologic recording equipment including microelectrodes with support hardware.	These objectives will necessitate a man-tended laboratory facility capable of supporting complex neurophysiologic testing. Animal centrifuges with controlled atmosphere, temperature, lighting, and waste collection will be required.
	2. <u>Vestibular Function - Provocative Response.</u> To assess the vestibular function in response to provocative stimuli from early through long-duration space flight.	2. Vestibular Function - Provocative Response a) Utilize the above methodologies of response recording while providing visual, rotational, and linear stimulation.			
	3. <u>Postflight Recovery/Analyses.</u> To trace the time course and characteristics of vestibular readaptation, and to assess the inflight and postflight results to determine the most appropriate animal species for further study.	3. Postflight Recovery/Analyses a) Continuation of the above studies.	Utilize the animals returned alive from space flight.	Vestibular Research Facility (on Earth).	

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of the Effect of Space Flight
on Vestibular Structure and Function

Category: Biomedical Problems/Vestibular

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Vestibular Function Study-Mammalian Vertebrates	1. <u>Vestibular Function-Normal Response.</u> To determine the initial change in vestibular function as well as the compensatory changes resulting from long-term exposure in a number of mammalian vertebrates maintained at various G levels. This will extend the nonmammalian studies to animals of a higher order.	1. Vestibular Function-Normal Response a) Electrode studies of afferent neural activity. b) Postural reflex, ocular counterrolling recording/monitoring c) Video recording of animal movement and body position d) EEG e) Monitor food, water consumption, and body weight	Rat: males 20 Total 4 preflight 16 inflight - 4 each at: 0-G, .1-G, .5-G, 1.0-G Cat: males 20 total 4 preflight 16 inflight - 4 each at: 0-G, .1-G, .5-G, 1.0-G Squirrel Monkey: males 20 total 4 preflight 16 inflight - 4 each at: 0-G, .1-G, .5-G, 1.0-G Rhesus Monkey: males 20 total 4 preflight 16 inflight - 4 each at: 0-G, .1-G, .5-G, 1.0-G	Neurophysiologic recording equipment including microelectrodes with support hardware.	These objectives will necessitate a man-tended laboratory facility capable of supporting complex neurophysiologic testing. Animal centrifuges with controlled atmosphere, temperature, lighting, and waste collection will be required.
	2. <u>Vestibular Function - Provocative Response.</u> To assess the vestibular function in response to provocative stimuli from early through long-duration spaceflight.	2. Vestibular Function - Provocative Response a) Utilize the above methodologies of response recording while providing visual, rotational, and linear stimulation.			
	3. <u>Postflight Recovery/Analyses.</u> To trace the time course and characteristics of vestibular readaptation. Assess the inflight and postflight results to determine the most appropriate animal species for further study.	3. Postflight Recovery/Analyses a) Continuation of the above studies.	Utilize the animals returned alive from space flight.	Vestibular Research Facility (on Earth)	

LIFE SCIENCES
ISSUE SUMMARY SHEET

BIOMEDICAL PROBLEMS

DISCIPLINE

ISSUE

IMMUNOLOGICAL

Assessment of the effect of space flight on the human immune system, including an investigation of the following questions:

- (1) What is the nature of the effect of long-term space flight on innate and acquired immunity?
- (2) Does long-term space flight produce a functional impairment in the ability of the immune system to respond to specific challenges?
- (3) Are the effects of long-term space flight on the immune system reversible upon return to Earth?

LIFE SCIENCES
INTEGRATED MISSION SCENARIO

Issue: Assessment of the Effect of Space Flight
on the Human Immune System

Category: Biomedical Problems/Immunological

Background

In early manned missions, alterations of plasma protein immunoprotein concentrations, responsiveness of lymphocytes, and numbers of leukocytes suggested potential alterations of cellular and humoral mechanisms. The Skylab and Shuttle missions also demonstrated postflight leukocytosis (neutrophilia), decreases in T-lymphocytes, decrease in T-lymphocyte function (response to mitogenic challenge), transient postflight elevation in B-lymphocytes, and the possible alteration in certain plasma proteins. Very little is known about the kinetics and function of leukocytes during exposure to long-term space flight. Therefore, in order to guarantee the immuno-competence of crewmembers, it is important to document the changes that occur in the immune system during long-term exposure to space flight.

MISSION LAUNCH DATE	MISSION NAME	MISSION OBJECTIVES
1997 (6-month inflight study)	Rodent Immunological Study	1. Space-flight Induced Changes 3. Lymphocyte Response 5. Postflight Recovery 2. Leukocyte Function 4. In vivo Lymphocyte Response
1999 (6-month inflight study)	Human Immunological Study	1. Space-flight Induced Changes 3. Lymphocyte Response 2. Leukocyte Function 4. Postflight Recovery

Mission Scenario Justification

The dynamic events related to the changes that take place in the human immune system during long-term space flight are not well understood. Therefore, it is important to accurately document the time course of any such changes in order to guarantee the immunocompetence of future crews involved in long-term space flight. The rodent experiments allow one to obtain tissue samples and to perform *in vivo* experiments that are either difficult or impossible to perform on humans. The human experiment will establish a baseline of normal immunological function during space flight and identify any significant changes that take place in the immune system. Based on the results of these experiments, further experiments may be required to elucidate the causative factors behind any significant changes in the immune system that may compromise man's ability to resist disease and infection during long-term space flight.

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of The Effect of Space Flight
on the Human Immune System

Category: Biomedical Problems/Immunological

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Rodent Immunological Study	1. <u>Space-flight Induced Changes.</u> To determine the time course of change in the rodent immune system, to provide a base-line of normal immunological status in the rodent and to validate the rodent as an appropriate model for the human immune response.	1. Space-flight Induced Changes a) Rodent sacrifice and histological examination of immunologically competent cells b) Differential leukocyte counts c) Immunoglobulin concentrations	Rodent: male 110 total Sacrifice schedule: 10 preflight 10/month 6 months inflight 10/week for four weeks postflight	Chemotaxic and phagocytic test chambers Incubated reaction chambers	All of these objectives require a man-tended laboratory system with controlled atmosphere, temperature, and lighting. This facility should be capable of supporting: animal sacrifices, histological studies, biochemical analyses of blood, the use of radioactive materials, and should be capable of housing the required number of rodents.
	2. <u>Leukocyte Function.</u> To determine if the functional capabilities of leukocytes in the rodent are altered due to long-term space flight.	2. Leukocyte Function a) Chemotaxis ability b) Phagocytic ability c) Adherence capability			
	3. <u>Lymphocyte Response.</u> To trace the long-term changes of T and B-lymphocyte responses to specific mitogenic challenges in the rodent.	3. Lymphocyte Response a) Cell proliferation b) Protein synthesis c) Electron microscopy			
	4. <u>In vivo Lymphocyte Response.</u> To determine the effects of space flight on the rodent's ability to form new humoral and cellular immunity components.	4. <u>In vivo</u> Lymphocyte Response a) Hypersensitivity reactions b) Antibody-forming potential c) Sensitized lymphocyte response d) Blood collections			
	5. <u>Postflight Recovery.</u> To trace the recovery of the rodent immunological system that has been exposed to long-term space flight.	5. Postflight Recovery Continuation of the space-flight induced changes, leukocyte function, lymphocyte response and <u>in vivo</u> lymphocyte response experiments on rodents returned from space flight.			

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Assessment of the Effect of Space Flight
on the Human Immune System

Category: Biomedical Problems/Immunological

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Human Immunological Study	1. <u>Space-flight Induced Changes.</u> To determine the time course of changes in the human immune system and to provide a baseline of normal human immunological status during space flight.	1. Space-flight Induced Changes a) Differential leukocyte counts b) Immunoglobulin concentration	Human 6 Total (Typical)	Chemotaxic and phagocytic test chambers Incubated reaction chambers	All of these objectives require a man-tended laboratory system with controlled atmosphere, temperature, and lighting. This facility should be capable of supporting the leukocyte and lymphocyte studies, including biochemical analyses of blood, blood counts, and the use of radioactive materials.
	2. <u>Leukocyte Function.</u> To determine if the functional capabilities of leukocytes in man are altered due to long-term space flight.	2. Leukocyte Function a) Chemotaxis ability b) Phagocytic ability c) Adherence capability d) Leukocyte life spans			
	3. <u>Lymphocyte Response.</u> To trace the long-term changes of T and B-lymphocyte responses to specific mitogenic challenges in the human.	3. Lymphocyte Response a) Cell proliferation b) Protein synthesis c) Electron microscopy d) Gravitation effects			
	4. <u>Postflight Recovery.</u> To trace the recovery of the human immunological system exposed to long-duration space flight.	4. Postflight Recovery Continuation of the space-flight induced changes, leukocyte functions, and lymphocyte response experiments on humans returned from long-duration space flight.			

LIFE SCIENCES
ISSUE SUMMARY SHEET

MEDICAL OPERATIONS SUPPORT STUDIES

DISCIPLINE

ISSUE

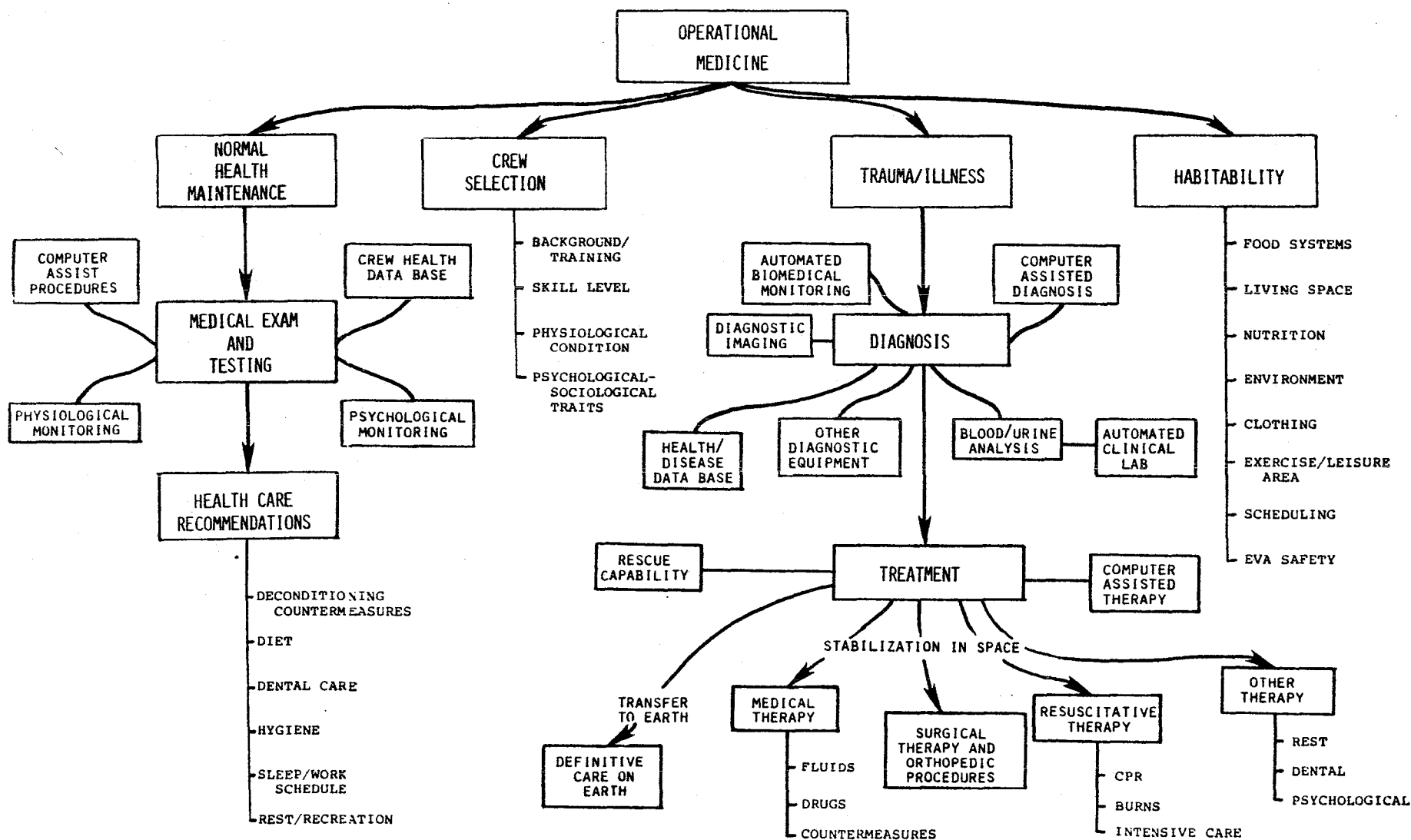
MEDICAL OPERATIONS

Experiments to support and enhance the capabilities of medical operations for a manned space station, including investigations of the following questions:

- (1) Is the incidence, treatment, and healing of trauma (e.g., skin lacerations, bleeding, bone fractures) in weightlessness identical to that in one-g?
- (2) Are the pharmacokinetics of drugs administered in space the same as those administered on Earth?
- (3) Can fluid infusion (i.v.) equipment be designed and developed to function in the absence of gravity? Are the fluid replacement protocols for hemorrhage the same as those for Earth-bound victims?
- (4) Which surgical equipment must be specially designed to function in zero-g? Must standard surgical techniques be altered for surgery in zero-g? Can a computer-assisted anaesthesia system be developed for use in zero-g?

MEDICAL OPERATIONS ACTIVITIES ON SPACE STATION

II/T/II



LIFE SCIENCES

INTEGRATED MISSION SCENARIO

Issue: Support Studies to Enhance the Capabilities
of Medical Operations

Category: Medical Operations

Background and Justification1. Treatment of Trauma

Accidents leading to trauma (skin breakage and bone fracture) will be among the most important medical considerations in space flight. As industrial tasks are added to the crew's duties, accidents producing crushing, punctures, and lacerations will become more common. There is no adequate characterization of tissue healing rates in zero-g, particularly for the bone and skin, tissues which are most susceptible to injury. The known alterations in calcium metabolism in zero-g suggest that bone healing may not be identical to that found in one-g. Healing of skin lacerations is governed primarily by physical forces (migration of fibroblasts and surface tension) and may not be expected to be changed in zero-g; however, this must be verified. Inasmuch as healing is preceded by an inflammation reaction, it is important to ascertain whether this process also is affected by gravity. Because bleeding usually accompanies trauma incidents, it is necessary to determine if clotting times are different in weightlessness. Consequently, three aspects of trauma will be studied in this overall experiment: bleeding and clotting, inflammation, and healing rates.

2. Drug Distribution (Pharmacokinetics)

Once a disease has been identified and an appropriate medication has been prescribed, the efficacy of that drug is dependent in large part on its concentration in the circulating blood. Pharmacokinetics refers to the process of drug transport from the site of ingestion or infusion of the drug to its site of action (e.g., specific or generalized cells or tissues). Knowledge of the pharmacokinetics of any drug forms the basis for predicting the dose-response and dose-frequency relationships. Four basic functions govern pharmacokinetics: absorption, distribution, metabolism, and excretion. Thus, anything which affects these functions will affect the efficacy of a drug. There is reason to believe that in zero-g, both absorption of certain substances from the gut and excretion are not the same as in one-g. Also, because body fluid volumes (including blood volume) are known to be reduced in weightlessness, the volume of distribution of any drug is reduced; consequently, its concentration is higher than it would be in a normal body fluid volume. However, pharmacokinetic studies using pharmacological agents have not been conducted during weightlessness. There is no need to test all drugs, but rather classes of drugs. For example, drugs may be classified on a pharmacokinetic basis according to whether they are actively excreted by the kidney, passively excreted by the kidney, or excreted by the lungs. The most important requirement for pharmacokinetic studies is a means to monitor drug levels in blood. In the mission experiment included in this package, an example is provided for the study of absorption of an arbitrary drug.

LIFE SCIENCES

INTEGRATED MISSION SCENARIO - Continued

II/1/II

3. Special Equipment Development and Evaluation

A space-borne medical facility for prolonged habitation will include much equipment that is found in emergency rooms, doctor's offices, and small clinics. This will include examination, diagnostic, and therapeutic equipment (i.e., surgical instruments, biomedical monitoring equipment, imaging systems, examination kits, biochemical and microbial analysis kits, computers, and fluid infusion kits). Some of this equipment can be obtained from an off-the-shelf inventory without further modification for use in space flight. Other instruments may need to be designed and manufactured to withstand non-medical environmental hazards such as vibration, heat, and temperature. However, another class of medical equipment must be specially designed to meet the particular medical requirements of operations in weightlessness. Such items include fluid infusion equipment which cannot rely on gravity feed or gravity-induced air bubble elimination. Also, certain equipment concerning surgical procedures and blood containment may need to be redesigned, since fluids and unrestrained tissues behave quite differently in zero-g. The present mission objective addresses the design and evaluation of this class of medical equipment.

MISSION LAUNCH DATE	MISSION NAME	MISSION OBJECTIVES
1992 (1 wk)	Treatment of Trauma	1. Bleeding and Clotting 2. Inflammation Response 3. Healing Rates
1992 (1 wk)	Drug Distribution (Pharmacokinetics)	1. Drug Absorption
1994 (2 wk)	Special Equipment Development and Evaluation	1. Fluid Infusion Equipment 2. Surgical Equipment 3. Computer-Assisted Anaesthesia System

LIFE SCIENCES
MISSION SUMMARY SHEET

Issue: Support Studies to Enhance the Capabilities of
Medical Operations

Category: Medical Operations

Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Treatment of Trauma 226	1. <u>Bleeding and Clotting</u> . To characterize bleeding processes from superficial vessels and to measure rates of <u>in vivo</u> and <u>in vitro</u> clotting times.	1. Bleeding and Clotting a) Perform lacerations of surface vessels, and perform video observations of bleeding b) Apply compression bandage, and measure <u>in vivo</u> clotting time c) Measure <u>in vitro</u> clotting time	Rodent: 10 each study	Surgical tools Bone fracture device Animal surgical bench Video microscope	These objectives require a man-tended laboratory that can be part of a first stage emergency clinic. It should be capable of supporting animals for several weeks, simple animal surgery, and a small workbench.
	2. <u>Inflammation Response</u> . To induce an inflammation reaction and to record details of the process.	2. Inflammation Response a) Excoriate skin with scalpel, add diphtheria toxoid, add cover slip, and bandage b) Change cover slip every 4-8 hours c) Stain, observe migration of cells (macrophages), and compare to one-g			
	3. <u>Healing Rates of Tissues</u> . To study rates of healing in muscle, skin, and bone, and to ascertain if healing rates are similar in zero-g and one-g.	3. Healing Rates Perform lesions, punctures, lacerations, and bone fractures on appropriately anaesthetized animals, and measure the healing of treated wounds			

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Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Drug Distribution	1. <u>Pharmacokinetics-Absorption.</u> To measure the absorption of an ingested drug from the gastrointestinal tract and compare it to doses administered intravenously (i.v.).	1. Pharmacokinetics-Absorption a) Ingest drug b) Measure blood levels at frequent intervals over a 2-hour period c) Compare with dose administered by i.v. d) Compare with 1-g measurements	Human 8 male 8 female	Drug analysis kit Simulation-model software	These objectives require a manned laboratory facility with controlled atmosphere, temperature, and lighting. This facility should be capable of supporting biochemical analyses of urine, plasma, feces, and the use of radioactive materials.
	2. <u>Pharmacokinetics-Excretion.</u> To measure the excretion of an ingested drug.	2. Pharmacokinetics-Excretion a) Ingest a radioactively-labeled drug b) Measure blood levels at frequent intervals over a 12-hour period c) Collect urine and fecal samples and measure the radioactivity of excretion d) Compute disappearance curves and compare to one-g studies			
	3. <u>Pharmacokinetics-Drug Maintenance.</u> To determine the relationships necessary to predict a dose-frequency profile for maintaining blood levels.	3. Pharmacokinetics-Drug Maintenance a) Develop a mathematical model for drug distribution, dose, frequency, and response b) Test the above model by administering multiple doses of a drug over a one-week period and monitoring blood levels			

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Mission Name	Mission Objectives	Experimental Studies	Specimen	Special Equipment	Special Space Station Attributes
Special Equipment Development and Evaluation	1. <u>Fluid Infusion Equipment</u> . To test a zero-g qualified fluid infusion system.	1. Fluid Infusion Equipment Test adequacy of fluid containers, infusion pumps, fluid lines, air bubble eliminator, and drug administrator	Large primate (20 kg), Chronically maintained 6 total	Fluid infusion system	These objectives require a manned laboratory facility with controlled atmosphere, temperature, and lighting. This facility should be capable of housing the required animals and a clinical research workbench, including a surgical bench, a microcomputer, and biomedical monitoring instruments.
	2. <u>Fluid Replacement After Hemorrhage</u> . To test the efficacy of the fluid handling system in counteracting a moderately severe hemorrhage.	2. Fluid Replacement After Hemorrhage Perform phlebotomy of 20% normal blood volume. Replace circulating blood with plasma volume expanders. Measure blood volume, blood pressure, and heart rate.			
	3. <u>Surgical Equipment</u> . To test a zero-g qualified surgical bench and operation field.	3. Surgical Equipment Perform sham operations (thoracotomy, lobectomy, laparotomy) under a sterile field, using specialized surgical equipment for restraining, retracting, and handling bleeding, etc.			
	4. <u>Computer-Assisted Anaesthesia System</u> . To test the capability of a computer-assisted monitoring/anaesthesia/life-support control system, in which the components tested will be: a) blood pO ₂ , blood pressure, heart rate, ECG, EEG, and body temperature monitors, b) an anaesthetic administration system, and c) an oxygen administration system.	4. Computer-Assisted Anaesthesia System Restrain subject and administer anaesthetic (without surgery). Administer oxygen as needed using computer control of physiological parameters.			

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